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(54) **Adaptively maintaining quality of service (QoS) in distributed PBX networks**

(57) An adaptation mechanism monitors, maintains and controls quality of voice-grade for communications among end-systems in a distributed PBX topology, thereby providing an enhanced Quality of Service (QoS) for the network.

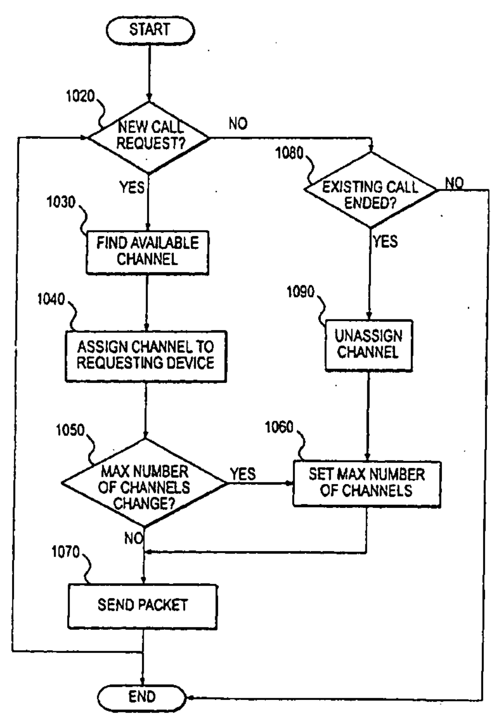

FIG. 10

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Description

[0001] The present invention relates to an adaptation mechanism which can be used to monitor, maintain and control quality of voice-grade for communications among end-systems in a distributed PBX topology, thereby providing an enhanced Quality of Service (QoS) for the network.

[0002] As shown in Fig. 1, a communication system 100 for an entity, such as a corporation, office, or home, would include a voice network 110, such as a private branch exchange (PBX), or a group of PBX's connected or communicating with each other or to a central office, and a data network 120, such as computers 125 connected to each other over an Intranet and to the Internet. PBX 110 is a network that allows many voice devices 115 to share a lesser number of outside lines (e.g., trunk lines) for making external voice calls. Internal wiring in PBX 110 permits users within the entity to contact each other without sending information outside of the entity.

[0003] As shown in Fig. 2, an entity may wish to connect voice devices 115 and computers 125 on a single network 200 for communication internally and externally to the Internet. In other words, voice network 110 and data network 120 would merge into a single network 200. Typically, network 200 digitizes the data from the voice devices into, for example, G.711 format, and sends all digital data, including the voice traffic, over network 200. In other words, network 200 would use the same manner of transmission between computers 125 and add additional processing to transmit data from the voice devices.

[0004] Fig. 3 illustrates a typical voice and data network 200. Fig. 3 includes a data network, such as a local area network (LAN), based voice switch (PBX) for transmission of voice data over a data link 310 using Internet protocol (IP). Voice devices, such as internal phones and external lines, are connected to a respective line card 320 or trunk card 330 contained in a remote or expansion cabinet 340 including a remote CPU 350 or shelf controller, via a respective line or channel. The cards 320 and 330 are selectively loaded into one of a plurality of slots 355 in expansion cabinet 340. Although a single expansion cabinet 340 is shown in Fig. 3, the PBX could include several expansion cabinets 340. Data link 310 connects expansion cabinet 340 to a switching matrix 360. Switching matrix 360 routes information from voice devices to other voice devices, internally through line cards 320 and externally through trunk cards 330. A process running on a master CPU 390 configures the present state of the switching matrix 360 over its backplane 380. Alternatively, master CPU 390 could be located apart from switching matrix 360 and the process running on master CPU 390 can configure switching matrix 360 over data link 310. Although each of the cards are shown as being loaded into an expansion cabinet 340, which is remote from the switching matrix 360, another implementation could include some cards in the same location, or physical cabinet, as master CPU 390. A computer 125 can also be connected to data link 310.

[0005] Master CPU 390 and remote CPU 350 cause packets of a defined size to be created for transmission over data link 310. These packets include information used to route the packet to a destination and the voice or data information. Fig. 4 illustrates a format of a typical packet 400 using an Ethernet data link 310. Packet 400 can include, for example, six bytes of a destination address 410, six bytes of a source address 420, 2 bytes of an indication of an ether type 430, a number of bytes of a data packet 440, containing data from multiple voice devices, and 4 bytes of frame check sequence (FCS) data 450. Data packet 440 includes header information for the transmission protocol, such as 20 bytes of IP header information 441 and 4-20 bytes of UDP/TCP header information 442, and data 443 for N channels. Typically, the PBX sends 8000 packets per second that include voice data.

[0006] Again referring to Fig. 3, to initiate a call to a destination voice device, a source voice device signals a source card (e.g., line card 320 or trunk card 330) to send a message to switching matrix 360. Switching matrix 360 sets the switching fabric of the network to create a link between the source and destination voice devices. When a call is initiated by a device on remote cabinet 340 by the device going off hook, a message is sent by the source device on remote cabinet 340 to a call server process running on master CPU 390 indicating that it is off hook. The call server process configures switching matrix 360 to connect the source device on remote cabinet 340 to a channel that provides a dial tone to the newly active device. When dialing begins at the source device on the remote cabinet 340, indicating a desired destination to contact, another message identifying the dialed destination is sent to the call server process running on master, which, in turn begins evaluating the dialed number to determine if it is valid. If the call server process determines that the number is valid, it then begins searching for the requested destination device. When the destination device is found, the call server process instructs the switching matrix 360 to establish a connection between the source and destination devices via switching matrix 360, thereby establishing a two-way speech path.

[0007] Fig. 5 illustrates a typical switching matrix 360 for parsing and creating a packet. A multiplexer/demultiplexer 500 receives and sends IP packets over data link 310. When receiving IP packets, the multiplexer/demultiplexer 500 takes the sequentially ordered channels and puts them into parallel order and sends this information to the switch 510. Conversely, when transmitting IP packets, the multiplexer/demultiplexer 500 takes the parallel ordered channels from the switch 510 and places them in sequential order to be included in an IP packet. Multiplexer/demultiplexer 500 outputs parallel data to a switch 510 or creates an IP packet. A table in switch 510 determines the channel positions in an IP packet.

Of course, in non-blocking mode, each voice device in the network will have a channel available for assignment by the switching matrix.

[0008] Fig. 6 illustrates a table consistent with a typical system for creating and parsing a packet. Table 600 provides a position index that shows where the data for each channel of, e.g., a network will be found in a packet. Although the packet positions are shown in groups of eight in Fig. 6, this is merely for the purpose of illustration. As shown in Fig. 6, all N channels of the network are presumed to be carrying information, regardless of whether the channel is active (off-hook), or even if a voice or data device is connected to the network at all.

[0009] Since a number of channels are typically unused, packets created using table 600 include superfluous information for the-unused channels, e.g., all zeros. In other words, the size allocated channels within the IP packet will be all zeros. This wastes the limited bandwidth of the network of Fig. 5. Bandwidth is the amount of traffic, in bits per second, that can be transmitted over a network. The size of packets and the rate at which the network sends the packets determines the bandwidth required for the application. Because each voice channel typically consumes 64 kilobits/second in an uncompressed format, if network 200 included a PBX having 1000 channels, network 200 would require at least 64 Megabits/second of bandwidth to transmit voice traffic. This is significant because data link 310 typically has a 100 Mbit/second bandwidth and, thus, voice traffic would consume almost two-thirds of the available bandwidth.

[0010] When such a large amount of the bandwidth is devoted to voice traffic, the network must spend much of its time processing the packets, which could yield very little information when many channels are inactive. Some data networks contain systems other than those carrying voice information. These systems also share the network's available bandwidth, consequently, having so much bandwidth devoted to voice traffic negatively impacts the overall network. For example, devoting such large amounts of bandwidth to voice traffic results in network congestion, leading to undesirable consequences such as delayed transmission, retransmission, and, indeed, losing packets altogether.

[0011] To reduce the amount of bandwidth devoted to voice traffic, insertion and deletion of cards connecting voice channel lines could be detected. Under this solution, however, all channels on inserted cards are transmitted across the network regardless of whether the channels are active or not, which is still inefficient utilization of bandwidth. In addition, this solution provides no bandwidth optimization when the network is fully loaded, i.e., when the maximum number of cards have been inserted.

[0012] To reduce the amount of bandwidth devoted to voice traffic, only channels that are active could be included in a changing table and packets would only transmit information regarding the active channels. Such a table must be updated on a real-time basis to define which calls are active and their position index, requiring additional CPU time or a faster CPU to reduce the impact of the real-time processing. In addition, additional synchronization messages must be sent and confirmed whenever a call is made or released to maintain the tables at the source and destination in synchronization. These synchronization messages consume some of the saved bandwidth.

[0013] Therefore, there is a need to efficiently reduce the amount of bandwidth required to transmit voice data in a network, using a minimum amount of additional hardware and processing, and a need to do so regardless of the number of active voice devices connected to the network.

[0014] An example of a bandwidth saving system and method using card detection is described in copending U.S. Patent Application Serial Number 09/474,779. An example of a bandwidth saving system and method using a changing table is described in copending U.S. Patent Application Serial Number 09/474,778.

[0015] Recently, many efforts have been devoted by the Internet community to investigate transport mechanisms capable of guaranteeing Quality of Service (QoS) requirements for datagram networks (such as, for example, Internet Protocol (IP) networks). The objectives include alternatives to the transport of voice, video and multimedia by classic Telephone/ISDN and ATM networks. The basic problem is how to guarantee bandwidth, latency (delay) and packet loss, required by voice and video, in datagram network architecture.

[0016] Communication links between PBXs require a fairly large bandwidth for operation on data networks. Maintaining this amount of bandwidth is expensive and often results in degradation in the overall quality of service among all applications running on the network. Known solutions to the problem include attempting to reserve bandwidth using approaches such as Resource reservation Protocols (RSVP) or policy management systems.

[0017] In addition, approaches to maintaining voice quality, such as setting up a fixed Packet Delay Variation (PDV) buffer size is not ideally suited to Internet Protocol (IP) Networks in which messages flow in a bursty, rather than uniform, manner. If the buffer size is too small, the most recently arriving data will overflow and the preceding data is lost. If the buffer is too large, there will be gaps, resulting in breaks between message packets. Attempts to set the buffer size at periodic intervals is a tedious process due to the redundancy of the traffic flow, and is usually based on trial and error.

[0018] Until now, the main obstacle to implementation of an adaptable QoS monitoring mechanism from an application prospect has been the manner in which measurements are obtained. Several algorithm-based solutions have been proposed, including using the Internet Control Message Protocol (ICMP). This, however, has been shown to produce not very accurate measure-

ments, has real-time impact on performance of the system, and adds more traffic to the network. The added traffic overhead is directly proportional to the level of accuracy being sought for the measurements.

[0019] Moreover, many real-time operating systems (RTOS) do not support multiple applications which use raw sockets (used mainly for ICMP). This usually results in interference between applications attempting to use the sockets.

[0020] Nor is using the Transmission Control Protocol (TCP) or the User Datagram Protocol (UDP) always acceptable, since these protocols add overhead onto both end systems, represented by the need to create at least one process on each end machine to simulate the functionality of the ICMP. Furthermore, processing time is added on because raw sockets interact directly with the network layer and other types of sockets interact with the upper layers of the IP stacks. This in turn results in inaccuracy in the sending and arrival time of messages. Furthermore, as in the case of ICMP, traffic is added to the network.

[0021] Systems and methods consistent with the present invention add intelligence to systems such as PBXs connected to a data network to react to changes in network conditions permitting communication links to quickly adapt to those conditions without the need for manual intervention and to reduce the impact of such systems on the network, thereby enhancing overall system performance.

[0022] Methods and systems consistent with the present invention are provided for monitoring the quality of data networks and dynamically adapting its behavior in accordance with the condition of the network to maintain QoS.

[0023] Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

FIG. 1 illustrates a prior communication system including separate voice and data networks; FIG. 2 illustrates a high level diagram of system having a combined voice and data network; FIG. 3 illustrates a more detailed diagram of the system of FIG. 2;
FIG. 4 illustrates the contents of a message sent in the network of FIG. 2;
FIG. 5 illustrates a switching matrix of the network of FIG. 2;
FIG. 6 is a table used to establish channel positions in an IP packet sent in the network of FIG. 2;
FIG. 7 illustrates a high level diagram of a system having a combined voice and data network consistent with the present invention;
FIG. 8 illustrates a more detailed diagram of system of FIG. 7;
FIG. 9 illustrates a switching matrix of the network of FIG. 7;
FIG. 10 is a flow chart of steps of the process for transmitting a message consistent with the present invention;
FIGS. 10a-10c are flow charts showing the steps of one embodiment of channel allocation and deallocation;
FIGS. 11a-11d illustrate the contents of a message sent in the network based on active communication detection;
FIGS. 12a-12c illustrate the contents of a message sent based on channel groups using active communication detection;
FIG. 13 illustrates the contents of a group of FIG. 12a-12c;
FIGS. 14a-14b illustrate the contents of a message sent in the network when groups are deallocated based on active communication detection;
FIG. 15 illustrates the contents of a message sent over the network based on active channel reordering to deallocate channel groups;
FIG. 16 is a flow chart of steps of the process for transmitting a message consistent with the present invention;
FIG. 17 is a table used to establish channel positions in an IP packet sent in the network of FIG. 7;
FIG. 18 illustrates transmission of an IP packet from a remote cabinet to a master cabinet consistent with the system of FIG. 7; and
FIG. 19 illustrates transmission of an IP packet from a master cabinet to a remote cabinet consistent with the system of FIG. 7.
FIG. 20 illustrates a PBX telephone system comprised of PBX main and expansion cabinets connected via a data network;
FIG. 21 illustrates the transmission of voice packets in a main or expansion cabinet;
FIG. 22 illustrates the reception of voice packets in a main or expansion cabinet;
FIG. 23a illustrates operation of a packet loss counter;
FIG. 23b further illustrates operation of a packet loss counter;
FIG. 24 is a diagram showing operation of packet round trip time calculation;
FIGS. 25a-25b illustrate operation of bandwidth optimization using idle card elimination;
FIGS. 26a, 26b and 26c illustrate operation of bandwidth optimization using priority-based card-elimination;
FIG. 27 is a flow chart detailing operation of a packet loss counter and system reaction;
FIG. 28 is a flow chart showing operation of packet delay variation measurement and system reaction; and
FIG. 29 is a flow chart diagram showing implementation of bandwidth optimization.

[0024] Reference will now be made in detail to the construction and operation of an implementation of the present invention which is illustrated in the accompany-

ing drawings. The present invention is not limited to this implementation but it may be realized by other implementations.

A. Overview

[0025] Systems and methods consistent with the invention provide an adaptation mechanism which can be utilized to monitor, maintain and control the quality of voice-grade communications among end-systems in a distributed Private Branch exchange (PBX) topology. Basically, incoming information from a data network is used to alter the behavior of a system and adjust the system's transmissions to the network. Such a communication link is able to adapt rapidly to changing conditions in the network without manual intervention, thereby quickly enhancing the overall system performance.

[0026] As shown in FIG. 1, a communication system 100 for an entity, such as a corporation, office, or home, would include a voice network 110, such as a private branch exchange (PBX), or a group of PBX's connected with each other or to a central office, and a data network 120, such as computers 125 connected to each other over an Intranet and to the Internet. PBX 110 is a network that allows many voice devices 115 to share a lesser number of outside lines (e.g., trunk lines) for making external voice calls. Internal wiring in PBX 110 permits users within the entity to contact each other without sending information outside of the entity.

[0027] As shown in FIG. 2, an entity may wish to connect voice devices 115 and computers 125 on a single network 200 for communication internally and externally to the Internet. In other words, voice network 110 and data network 120 would merge into a single network 200. Typically, network 200 digitizes the data from the voice devices into, for example, G.711 format, and sends all digital data, including the voice traffic, over network 200. In other words, network 200 would use the same manner of transmission between computers 125 and add additional processing to transmit data from the voice devices.

[0028] FIG. 3 illustrates a typical voice and data network 200. FIG. 3 includes a data network, such as a local area network (LAN) based voice switch (PBX) for transmission of voice data over a data link 310 using Internet protocol (IP). Voice devices, such as internal phones and external lines, are connected to a respective line card 320 or trunk card 330 contained in a remote or expansion cabinet 340 including a remote CPU 350 or shelf controller, via a respective line or channel. The cards 320 and 330 are selectively loaded into one of a plurality of slots 355 in expansion cabinet 340. Although a single expansion cabinet 340 is shown in FIG. 3, the PBX could include several expansion cabinets 340. Data link 310 connects expansion cabinet 340 to a switching matrix 360. Switching matrix 360 routes information from voice devices to other voice devices, internally through line cards 320 and externally through trunk cards 330. A process running on a master CPU 390 configures the present state of the switching matrix 360 over its backplane 380. Alternatively, master CPU 390 could be located apart from switching matrix 360 and the process running on master CPU 390 can configure switching matrix 360 over data link 310. Although each of the cards is shown as being loaded into an expansion cabinet 340, which is remote from the switching matrix 360, another implementation could include some cards in the same location, or physical cabinet, as master CPU 390. A computer 125 can also be connected to data link 310.

[0029] Master CPU 390 and remote CPU 350 cause packets of a defined size to be created for transmission over data link 310. These packets include information used to route the packet to a destination and the voice or data information. FIG. 4 illustrates a format of a typical packet 400 using an Ethernet data link 310. Packet 400 can include, for example, six bytes of a destination address 410, six bytes of a source address 420, 2 bytes of an indication of an ether type 430, a number of bytes of a data packet 440, containing data from multiple voice devices, and 4 bytes of frame check sequence (FCS) data 450. Data packet 440 includes header information for the transmission protocol, such as 20 bytes of IP header information 441 and 4-20 bytes of UDP/TCP header information 442, and data 443 for N channels. Typically, the PBX sends 8000 packets per second that include voice data.

[0030] Again referring to FIG. 3, to initiate a call to a destination voice device, a source voice device signals a source card (e.g., line card 320 or trunk card 330) to send a message to switching matrix 360. Switching matrix 360 sets the switching fabric of the network to create a link between the source and destination voice devices. When a call is initiated by a device on remote cabinet 340 by the device going off hook, a message is sent by the source device on remote cabinet 340 to a call server process running on master CPU 390 indicating that it is off hook. The call server process configures switching matrix 360 to connect the source device on remote cabinet 340 to a channel that provides a dial tone to the newly active device. When dialing begins at the source device on the remote cabinet 340, indicating a desired destination to contact, another message identifying the dialed destination is sent to the call server process running on master, which, in turn begins evaluating the dialed number to determine if it is valid. If the call server process determines that the number is valid, it then begins searching for the requested destination device. When the destination device is found, the call server process instructs the switching matrix 360 to establish a connection between the source and destination devices via switching matrix 360, thereby establishing a two-way speech path.

[0031] FIG. 5 illustrates a typical switching matrix 360 for parsing and creating a packet. A multiplexer/demultiplexer 500 receives and sends IP packets over data link 310. When receiving IP packets, the multiplexer/de-

multiplexer 500 takes the sequentially ordered channels and puts them into parallel order and sends this information to the switch 510. Conversely, when transmitting IP packets, the multiplexer/demultiplexer 500 takes the parallel ordered channels from the switch 510 and places them in sequential order to be included in an IP packet. Multiplexer/demultiplexer 500 outputs parallel data to a switch 510 or creates an IP packet. A table in switch 510 determines the channel positions an IP packet. Of course, in non-blocking mode, each voice device in the network will have a channel available for assignment by the switching matrix.

[0032] FIG. 7 illustrates a high level diagram of a network 700 consistent with the present invention. Network 700 includes a system to transmit voice data over a data network, e.g., a LAN-based voice switch (PBX) over a data link 710 using Internet protocol (IP). Other data networks could also be used. Voice devices, such as internal phones and external lines, are connected to a respective line card 720 or trunk card 730 contained in an expansion cabinet 740, including a remote CPU 750, via a respective line or channel. The cards 720 and 730 are selectively loaded into one of a plurality of slots 755 in the device. Although a single expansion cabinet 740 is shown in FIG. 7, the PBX could include several expansion cabinets.

[0033] Data link 710 connects expansion cabinet 740 to a switching matrix 760. Data link 710 could be a single line or a multi-hop network. Switching matrix 760 routes information from voice devices to other voice devices, internally through line cards 720 and externally through trunk cards 730.

[0034] A process running on a master CPU 790 configures the present state of the switching matrix 760 over its backplane 780. Alternatively, master CPU 790 could be located apart from switching matrix 760 and the process running on master CPU 790 can configure switching matrix 760 over data link 710. Although each of the cards are shown as being loaded into an expansion cabinet 740, which is remote from the switching matrix 760, another implementation could include some cards in the same cabinet as master CPU 790. One or more computers 795 can also be connected to data link 710.

[0035] Remote CPU 750, switching matrix 760, and master CPU 790 could be a number of machines, a separate machine, or a portion of a machine. For example, as shown in FIG. 8, each of remote CPU 750, switching matrix 760, and master CPU 790 could reside in cabinets that communicate via data link 710. For example, each of cabinets 800, 840, and 880 includes a memory 801, 841, and 881; secondary storage 802, 842, and 882; a central processing unit (CPU) 790, 843, and 883; an input device 804, 844, and 884; a video display 805, 845, and 885; and slots 806, 846, and 886. One skilled in the art will appreciate that cabinets 800, 840, and 880 may contain additional or different components and that each cabinet could include the same hardware as the other cabinets or different hardware. Each of memories 801, 841, and 881 includes an operating system 807, 847, and 887; a TCP/IP protocol stack 808, 848, and 888; a card or an active communication detection program 809, 849, and 889; a table management program 810, 850, and 890; and a communication program 811, 851, and 891.

[0036] A set of cards is loaded onto slots 806, 846 and 886. Typically, cabinets 800, 840, and 880 would include at least ten slots. Each of the cabinets also includes a switching matrix. In a master/slave configuration, one of the cabinets (the "master cabinet"), for example cabinet 800, would include the master CPU 790 and the switching matrix 760. Other cabinets 840 and 880 include remote CPUs 843 and 883 and switching matrixes 855 and 895, and are referred to as the remote or expansion cabinets. In a centralized master/slave configuration, only the switching matrix of the master cabinet establishes and terminates two-way speech path connections and is thus referred to as the master switching matrix. In other configurations, the switching matrices of the remote cabinets could also establish and terminate two-way speech path connections with, for example, other voice devices connected to the same remote cabinet. In this case, the master cabinet could supervise the remote cabinets.

[0037] As shown in FIG. 9, each of switching matrixes 760, 855, and 895 include a multiplexer/demultiplexer 900 and a register 910. Although register 910 is shown as separate from multiplexer/demultiplexer 900, multiplexer/demultiplexer 900 and register 910 could be combined in a single device. Multiplexer/demultiplexer 900 formats and receives packets sent over data link 710 and outputs parallel data to a switch 920 or an IP packet to data link 710, using, for example, a field programmable gate array. Register 910 stores a value that indicates the maximum channel number in the packet. This value is used to set the packet length. When a packet is received, switch 920 places the parallel data from the demultiplexer 900 onto the appropriate channel in the cabinet based on setup information from driver 930. When a packet is to be sent, switch 920 places the data for each active channel detected onto an input of the multiplexer 900 based on setup information from driver 930 so that a packet can be formed.

[0038] As will be explained below, register 910 maintains a value based on the number of cards detected in a particular cabinet at a particular time. PBX applications are capable of transmitting a number of voice channels on a periodic basis. For example, 320 voice channels may be transmitted every 125 microseconds per link, giving rise to a bandwidth of 30 Mbps (voice + signaling, one byte per channel). Since voice packets occupy the largest share of this bandwidth, a system consistent with the invention derives certain measurements as an indicator of network behavior and dynamically adapts the system to insure that a certain level of Quality of Service is maintained at all times.

[0039] Recent developments introduced by Nortel

Networks, have resulted in the capability of PBXs being extended, by providing distributed PBX communication capability over data networks.

[0040] The Option 11C system manufactured by Nortel Networks is a version of the Meridian-1 System constituting an integrated Private Branch Exchanges telephone system which has the capability of handling integrated voice and data communications on a single-site system or directly networked with a number of other Option 11C systems. Option 11C/Meridian-1 systems are mentioned as examples of systems wherein the principles of the invention may be advantageously used.

[0041] However, it will be apparent from the description herein that the invention may also be used advantageously in a variety of other types of systems and networks.

B. Architecture

[0042] Fig. 10 illustrates a flow chart of the steps of the operation of the network 700 including the cabinets of Fig. 8 in accordance with principles of the present invention.

[0043] Initially, the table management program 810 in the master cabinet 800 calls card detection program 809 (step 1000). At start up, card detection program 809 polls the slots in cabinet 800 to detect whether a line or trunk card is loaded onto a respective slot. In some implementations, the master cabinet would be configured to not contain any cards, and this polling could be omitted. For the slots of the other cabinets, the card detection program 809 instructs the expansion cabinets to run the other card detection programs 849 and 889, so as to detect whether a line or trunk card is loaded onto their respective slots and to report the results of the detection to master cabinet 800. In other implementations, the card detection programs 849 and 889 could detect cards on their respective remote cabinets without prior instruction from master cabinet 800 and report the results of the detection to master cabinet 800.

[0044] Based on the cards detected, table management program 810 creates a table defining the packet position index for each channel (i.e., identifying where information for a line will be placed in a packet) for each cabinet (step 1010). For example, channels for each card present in the remote cabinets will be assigned a position in the data packet. In a typical PBX setup, a card will have a maximum of 32 units. Typically, a voice device will be connected to each unit on a given card. Other setups could include more or less units per card for each respective card.

[0045] A number of options are available for setting up a table. For example, table management program 810 could simply assign packet positions 1-32 for the first card detected, packet positions 33-64 for the next card detected, and so on. Alternatively, card detection program 809 could also detect characteristics of the card, such as the number of channels that a card supports or the type of card (digital, analog, etc.), and the table management program 810 would assign only as many packet positions for a card as the card can support or packet positions based on the type of card. Also, if slot 3 contained a card, packet positions 1-96 could be assigned for cards 1-3, regardless if slots 1 and 2 contained cards. Similarly, the table management program 810 could assign packet positions for channels based on the lowest numbered slot and the highest numbered slot that contains a card, for example, if a card is detected in slots 2 and 5, packet positions 1-128 could be assigned to the channels of slots 2-5, regardless if slots 3 and 4 contained cards. These options could also be combined. Based on the detected information, table management program 810 also computes the maximum number of channels that will be sent in a packet for each table.

[0046] Fig. 17 illustrates a card detection table 1100 consistent with the present invention when card detection program 809 detects the number of channels that a card supports. In Fig. 17, a cabinet includes five slots, and card detection program 809 detects three cards resident in slots 1, 3, and 4, respectively. Card detection program 809 determines that the card in slot 1 (card 1) is an 8-channel card, and the cards in slots 3 and 4 (cards 3 and 4) are each 4-channel cards.

[0047] To populate table 1100 for this cabinet, because card 1 is a eight channel card, the table management program assigns packet positions 1-8 to the first eight channels of card 1 and indicates a zero value to the 24 remaining channels, meaning that the card is detected but the channel is not used and the channel is not transmitted. Similarly, channels 1-4 of card 3 and channels 1-4 of card 4 are assigned packet positions 9-16, respectively, and the remaining 28 channels are set to a zero value. A predetermined value, such as -1, is assigned to all 32 channels when a card is not detected in a particular slot (e.g., cards 2 and 5) and the channels for the slot are not transmitted. The value currently stored in register 910, if any, is updated to 16, which is the maximum channel number based on the cards detected at this time. Of course, Fig. 17 merely presents an example of a way to populate a table. In some circumstances, the channels in a card may be arranged in a non-sequential, repeating manner (for example, channels of card 1 may be arranged 1, 9, 17, 25, 2, 10, 18, 26, 3,...).

[0048] Once the table management program 810 populates a table for each remote cabinet in the network, the cabinets are synchronized so that the master cabinet and each remote cabinet can create and parse packets consistent with the respective tables (step 1020). In one implementation, the table management program of the master cabinet sends all tables to table management programs of the other cabinets and, thereby, synchronizes the cabinets, or instructs the other cabinets to independently create its own table. Since repeatedly sending large tables could tax system resourc-

es and delay start up of network 700, master cabinet 800 could send each of the other cabinets the position index for the first channel of each card in the respective other cabinets or for the first card in the respective other cabinets. The other cabinets would then calculate the position indexes of the other channels and the maximum number of channels. For example, to inform a cabinet of the structure of table 1100, cabinet 800 would send a message to the cabinet that card I has a position index beginning at 1, card 3 has a position index beginning at 9, and card 4 has a position index beginning at 13. The message could take various forms, such as a portion of a voice message, a portion of a call-setup message, a portion of connection status, or "heartbeat", message, or a dedicated message. In other implementations, each of the table management programs of the remote cabinets could calculate their own table and may inform the master cabinet of the format of their respective table. This would lessen the processing burden on the master cabinet. Of course, the card status information could be sent to the master cabinet for each remote cabinet so that the master cabinet can store the card status information and independently create or update the tables, as previously mentioned.

[0049] After the cabinets are synchronized, the network is ready to process voice data and the table management program instructs the communication program to begin processing voice calls (step 1030). Various methods are available for processing voice calls. For example, when a voice device requests communication, the cabinet including the voice device sends a request to the master cabinet, including an indication of a destination voice device. For ease of explanation, assume that this request is made with a single message, although various messages could be sent to initiate the link between the source and destination voice devices, such as those used in a signaling request or signaling messages. These signaling messages indicate that a voice device has gone off-hook and that dialing has been initiated. Initially the table in the master cabinet 800 is empty, but it begins to fill as new calls are requested on the network. Upon receipt of the indication of the destination, the master cabinet 800 determines if the call is a new call requiring assignment of a new channel, i.e., a reconfiguration of switching matrix 760 (step 1020).

1. Channel Allocation and Deallocation

[0050] If the call is a new call, the master cabinet then searches for the first available channel and sets switching matrix 760 so that the hardware in the master cabinet listens to the source and destination devices and exchanges the voice communication between the source and destination devices (step 1030). Particularly, switching matrix 760 loads the tables corresponding to the source and destination cabinets so that packets will be created based on the cards detected.

[0051] Simultaneously with the processing of voice calls, e.g., the table management program detects if card status has changed by, e.g., the removal of a card or the addition of a new card (step 1040), either continuously, based on event-notification, or at predetermined intervals. "Removal" of a card includes physical removal and/or operational removal, as when a card is disabled by a malfunction. Card detection program 809 determines if card status has changed in a number of ways. For example, each time a card is added or removed, an expansion cabinet associated with the card could send a message to card detection program 809. Alternatively, an installer could manually notify card detection program 809 using an input device. In these schemes, card detection program 809 could determine the highest slot on which a card resides in a given cabinet and only look for added cards beyond this point, trading off bandwidth optimization for ease of processing. If card status changes for a particular cabinet or cabinets, the table management program of the master or remote cabinets adjusts the table in accordance with the detected change in card status (step 1050).

[0052] Various options are available to adjust the tables. The adjustment could take place on a first-come basis. Instead, removal of cards can be dealt with first, to free up available packet positions for new cards. The packet positions corresponding to the removed card could be filled by shifting the packet position indices of the cards following the removed card into the packet position indices of the removed card. Instead, the packet position indices of the last card detected, including a newly-added card, could be assigned to the packet position indices of the removed card, assuming that a newly-added card and a removed card have similar characteristics.

[0053] When cards are added, a first-come option assigns packet positions subsequent to the last card detected to the new card. This could lead to a logical assignment of packet positions that is different from the physical configuration of slots. For example, if cards are detected in slots 1 and 3 at start-up, and a card is added to slot 2 during operation, a table consistent with the present invention could assign packet positions 1-64 to cards 1 and 3, and packet positions 65-96 to card 2. Alternatively, the table management program could assign the packet positions from scratch, that is sequentially assign the packet positions 1-96 to cards 1, 2, and 3, for example. The option used for establishing tables during start-up can also be employed when adjusting the tables or another option could be employed. The decision of which table option to use could be based on a detected system parameter, such as the quality of network service or a current load on a CPU.

[0054] After the table(s) are adjusted, the tables of the remote and master cabinets are synchronized (step 1060), in a manner similar to step 1020, and the table management program 810 continues to wait for card status to change again (step 1040). Because the system can operate substantially in real-time, the sending of

voice messages based on the new table format could be inhibited until the tables of the particular remote cabinet and the master cabinet are synchronized using handshaking. Typically, this handshaking is not required, and the voice messages could be sent and cached or even lost, because the synchronization would take a brief time, such as less than a few seconds.

[0055] As an example, Fig.18 illustrates packet formation consistent with the architecture of Figs. 7-9 for packets sent between cabinet 840 and master cabinet 800. Assume, for example, that unit 3 of slot 1 in cabinet 840 wishes to communicate with unit 3 of slot 3 in cabinet 840 and that the master cabinet contains the only switching matrix that routes calls to voice devices. Further assume that slot 2 of cabinet 840 is empty.

[0056] To initialize a communication session, the call processing program in master cabinet 800 configures switching matrix 760 to connect unit 3 of slot 1 in expansion cabinet 840 with unit 3 of slot 3 in expansion cabinet 840 in accordance with the table for the expansion cabinet. An exemplary table for cabinet 840, consistent with the present invention, could set unit 3 of slot 1 in packet position 3, and unit 3 for slot 3 in packet position 35 (i. e., as if slot 3 were slot 2). After master cabinet 800 sets up the switching matrix 760, the units in cabinet 840 send voice information.

[0057] As shown in Fig. 18, the communication program in cabinet 840 "listens" to unit 3 of slot 1 and unit 3 of slot 3 and places information from these units on, e.g., output positions 3 and 35 of switching matrix 844, respectively, based on the table for cabinet 840. Multiplexer 900 then polls the switching matrix to place the information from the units in the appropriate packet positions 3 and 35. Because the multiplexer 900 knows the maximum channel number, multiplexer 900 will indicate that the packet is complete upon processing the maximum channel number. Data link 710 then transmits the packet to master cabinet 800, where the packet is demultiplexed and sent to switching matrix 760. Switching matrix 760 is configured to send information from packet position 3 to packet position 35 and vice versa.

[0058] As shown in Fig.19, master cabinet 800 then creates an IP packet to be sent to cabinet 840. Multiplexer 900 of the master cabinet then polls the switching matrix 760 to place the information from the packet position 3 into packet position 35 and from packet position 35 into packet position 3. Because the multiplexer 900 knows the maximum channel number, multiplexer 900 will indicate that the packet is complete upon processing the maximum channel number. Data link 710 then transmits the packet to cabinet 840, where the packet is demultiplexed and sent to the appropriate voice unit. Thereby, voice information can be transferred between the source and destination voice devices.

D. Conclusion

[0059] Card detection allows systems and methods consistent with the present invention to reduce the amount of bandwidth required to transmit voice data in a network, by reducing the size (length) of the packet. Because card status is changed infrequently, these systems and methods use a minimum amount of additional hardware and processing.

[0060] Particularly, active communication program 809 loads the tables corresponding to the source and destination cabinets so that packets will be created based on the active (busy), channels. This minimizes the size of the packet to include only those channels that are active. This reduction in size, in turn minimizes the bandwidth required to transmit the packet. In one implementation the master cabinet searches for the first available channel when a new call request is made, however, the searching techniques are not limited to searching for the first available channel only. Typically if a previously active channel has gone inactive, the active communication detection program 809 (where "communication" includes any communication device) will assign this channel to the new call.

[0061] After the receipt of a new call request, and a search for an available channel, the active communication detection program 809 will assign a channel to the voice device requesting a new call (step 1040). If, as mentioned above, the active communication detection program 809 locates a newly inactive channel during its search, it will assign this channel to the new call. If, however, no recently inactive (idle) channels are found, the new call will be assigned a new inactive channel at the end of the table.

[0062] In one implementation, if no new call requests are made and there are no existing calls on the network, i.e., no active channels, then no channels will be transmitted at all. If, however, a new call request is made and after searching for the first available channel, the active communication detection program 809 finds no inactive channel to assign to the new call, it will allocate and assign a new channel to the call. As shown in Fig. 11a, the new call will be assigned channel 1 in the data segment 1111 of the packet 1110. If another call request is made before channel 1 goes inactive, the new call will be assigned channel 2 in the data segment 1121 of the packet 1120 as shown in Fig. 11b. This process will continue until the maximum number of channels on the network are active, and as shown in Fig. 11c, all will be included in the data segment 1131 of the packet 1130. Notice that the size of the packets 1110 - 1140 varies depending upon the number of active channels on the network. As channels are added, the packet size increases, and as channels are removed, the packet size decreases. As mentioned above, this variation in size varies the amount of bandwidth required to transmit the packets across the network.

[0063] In another embodiment, the active communication detection program 809 initially allocates a group of channels. As shown in Fig. 12a, this group is included in data segment 1211 of a packet 1210. The group could

consist of a single channel, or the maximum number of channels, or any number in between. In addition the group of channels could be any variation of the channels located on inserted cards in a cabinet, i.e. if the fourth channel on the second card in a cabinet becomes active, then the group could consist of all channels on the first card and all channels up to channel 4 on the second card.

[0064] The channels within the allocated group are initially inactive. As new call requests are received, the active communication detection program assigns the calls to the channels within the group. When all channels within the group are assigned, a new group of channels are allocated upon receipt of the next call request. The new group is included in the data segment 1221 of the packet 1220 as shown in Fig. 12b. This process continues until all groups, which corresponds to all available channels, are assigned. When this occurs, all groups will be included in the data segment 1231 of a packet 1230.

[0065] In one embodiment of the invention, the groups consist of 16 channels as shown in Fig 13. Initially a first group of 16 inactive channels is allocated. When the number of active channels within the group reaches a number equaling the maximum number of allocated channels minus five, a new group is allocated. This process continues until all groups have been allocated.

[0066] After the call is assigned a channel, the active communication detection program 809 then determines if the maximum number of channels to be transmitted has increased (step 1050). As pointed out above, if a recently inactive channel is found during the search for a channel, then the new call will be assigned to this channel. If this is the case, then the maximum number of channels to be transmitted does not increase. In contrast, if no newly inactive channel is found during this search, then the active communication detection program 809 will assign a new channel to the new call request. If this is done, the active communication detection program 809 will increase the maximum number of channels to be transmitted and inform the multiplexer 900 to set the new maximum number of channels (step 1060).

[0067] The active communication detection program 809 then loads the tables corresponding to the source and destination cabinets so that packets will be created and transmitted based on the active channels (step 1070).

[0068] As has been previously explained, the active communication detection program 809 will include active channels in messages that are sent across the network. In addition to this, the channel detection program 809 will end transmission of a channel once it has become inactive based on signaling from a source or destination device requesting call termination. If the active communication detection program 809 determines that there are no new call requests at step 1020, it will then determine if any previously active calls have become inactive (step 1080). If this is the case, the active communication detection program 809 will un-assign the inactive channel so that it is no longer included in the voice packet (step 1090).

[0069] Referring to Figs. 11c and 11d, if, for example, the maximum number of channels were active, all would be included in the data segment 1131 of a packet 1130. Assuming the maximum number of channels is greater than four, assume that all channels go inactive except the first four channels. These remaining active channels will be included in the data segment 1121 of a packet 1130, the others having been unassigned. Note, however, that in this example all channels except the first four became inactive and consequently those four are transmitted. Thus packets transmitted over the network during one transmission may be of a different size during another transmission based on call activity.

[0070] This concept also applies to groups of channels that have been allocated. For example, suppose three groups of 16 channels have been allocated and all channels are active, if a certain number become inactive, the active communication detection program will deallocate a group. In one embodiment, if the number of active channels falls below a number equaling the total number of allocated channels minus 21, then a group will be deallocated. Note that in this embodiment, this implies that one group of 16 channels is always allocated. This is shown in Figs. 14a and 14b. Fig. 14a shows three groups of 16 channels allocated with all channels active, then channels 27-48 going inactive. Because the remaining number of active channels, 26, is less than 27, which represents the total number of allocated channels, 48, minus 21, the third group is deallocated. The resulting packet 1420 to be transmitted with the remaining two groups in the data position 1421 is shown in Fig. 14b.

[0071] When a previously active channel is un-assigned, the maximum number of transmitted channels is decreased, and the active communication detection program 809 will inform the multiplexer 900 to set the new maximum number of channels (step 1060) by setting the register 910. The process for sending a packet is then repeated.

[0072] As outlined earlier, the present invention will assign and unassign channels as they become active and inactive, respectively. Figs. 10a-10c illustrate the steps of channel assignment and unassignment. Fig. 10a illustrates the channel assignment process. First, a signaling message indicating that a voice device has gone off-hook is received (step 2000). This message contains the IP port number connected to the data link 710 for the voice device. The slot number for the voice device is then determined based on the location of the voice device (step 2010), i.e. based on which expansion cabinet the voice device is connected to. If the unit does not have a channel assigned to it, (step 2020), then a search for the first available channel will be conducted (step 2030). Once the channel is found, it will be as-

signed to the requesting voice device and marked "active" (step 2040). If this causes the maximum number of channels included in a packet to change, (step 2050), then the maximum number of channels will be reset to this new value (step 2060). A data message is then sent to the other cabinet indicating the physical connection information of the voice device such as its unit and slot number as well as the channel number (step 2070). This message could take various forms, such as a portion of connection status, or "heartbeat" message, or a dedicated message. The switching matrix 760 is then reconfigured according to the new channel assigned to the voice device (step 2080).

[0073] Channel unassignment, shown in Fig. 10b operates in a similar manner. A signaling message is received indicating channel and slot number of the voice device that has gone inactive (step 3000). A search for the unit number is then conducted (step 3010). If the voice device had a channel assigned to it, the channel is unassigned and marked inactive (step 3030). If this changes the maximum number of channels to be included in transmitted packets (step 3040), then the maximum number of channels is reset to the new value (step 3050). A message is sent to the other cabinet indicating that a channel has been deallocated (step 3060). This message could take various forms, such as a portion of a voice message, a portion of a call-setup message, a portion of connection status, or "heartbeat" message, or a dedicated message.

[0074] Figure 10c is an infinite loop that waits for the signaling messages mentioned in the above explanations. It listens for the data messages from steps 2070 and 3060 of Figs. 10a and 10b, respectively. If a message is received (step 4010), then it determines if a channel needs to be assigned or unassigned (step 4020). If a channel needs to be assigned, it is assigned (step 4040), however, if a channel needs to be unassigned, it is unassigned (step 4030). If the maximum number of channels that is to be included in a packet to be transmitted changes, (step 4050), the maximum number of channels is reset (step 4060).

[0075] Typically, the channel allocation and deallocation processes of Figs. 10a and 10b run on the main cabinet and the process of Fig. 10c runs on the expansion cabinet. However, if the processes of 10a and 10b are divided among the main and expansion cabinet, then the process of 10c must be located on each cabinet. This is because if the main cabinet performed the process of Fig. 10a (channel assignment) only, it would have no way of knowing when channels were unassigned because channel unassignment is being done by the expansion cabinet, and vice versa. It should be noted that these three processes may be divided among the main and expansion cabinets in any combination provided that if the processes of Figs. 10a and 10b are on separate cabinets, the process of Fig 10c must be located on all cabinets.

2. Active Channel Reordering

[0076] In order to further minimize the size of IP packets transmitted over the network thus minimizing the bandwidth required to transmit those packets, the present invention also reorders the remaining active channels after previously active channels within a packet have gone inactive. Referring back to Figs. 11c and 11d, suppose all channels of packet 1130 of Fig 11c became inactive except 4. Regardless of the channel positions of the 4 remaining channels of packet 1130 of Fig 11c, the master switching matrix will unassign the inactive channels and reorder the remaining 4 active channels to minimize the size of the packet to be transmitted. Thus, the new packet will take the form of the packet 1140 of figure 11d. Therefore, after detecting and unassigning channels that have become inactive, the active communication detection program will reorder the remaining active channels in order to minimize the size of the packet. The channels could be reordered by shifting the remaining active channels, or by reassigning the last active channel in the packet to the newly inactive position. For example, if channels 1-20 were active and channel 2 goes inactive, channels 3-20 could be shifted to the right by one channel position, or channel 20 could be reassigned to channel position 2.

[0077] Active channel reordering also applies to channel groups as shown in Fig. 15. If, for example, after three groups are allocated, channels become inactive in a random manner, the active communication detection program 809 will reorder the remaining active channels such that the number of allocated channel groups is kept to a minimum. In this example, group 3 will be deallocated after the reordering.

3. Packet Formation and Transmission

[0078] FIGs. 18 and 19 illustrate an example of packet formation and transmission consistent with architecture of Figs. 7-9 and the present invention for packets sent between cabinet 840 and master cabinet 800. It should be noted that in this example the voice devices were located on the same cabinet 840, but the voice devices may be located on separate cabinets. As shown in Fig. 18, when channel 10 of cabinet 840 wishes to communicate with channel 5 of cabinet 840, assuming channel 5 of cabinet 840 is inactive, cabinet 840 will send a request to master cabinet 800 to assign a channel for the device connected to channel 10.

[0079] Master cabinet 800 searches for an inactive channel and allocates, in this example, channel 4 on the IP packet. Master cabinet 800 then sends this message to cabinet 840. As the number is being dialed by the device connected to channel 10 indicating that it would like to connect to channel 5, the master cabinet determines if the destination is valid. As shown in FIG. 19, once the master cabinet 800 determines that the destination is valid, it then searches for the first available channel and

assigns a channel for the destination device as well as sets the new maximum channel number if a new maximum number needs to be set. In this example, the channel for the destination device - channel 5 is assigned channel max. The master cabinet 800 then sends a message to cabinet 840 with this information.

[0080] The two-way speech path is then established between the two devices by the master cabinet 800. The information received in packet position 4 is routed by the master cabinet 800 to packet position max. Conversely, the information received from packet position max is routed by the master cabinet 800 to packet position 4 thus allowing the devices connected to channels 10 and 5 to communicate with one another.

[0081] Referring now to FIG. 20, an objective of the aforementioned development is to provide the capability to support communication (including voice) between two or more PBXs over a data network, such as an IP LAN 10. In one configuration, one PBX 12 acts as a master (also referred to as the main cabinet) containing a master CPU and master switching matrix and the other PBXs 14 are slaved (also referred to as the expansion cabinets).

[0082] Communication between the PBX cabinets comprises groups of voice and other packets. The voice packets are transmitted periodically, and are fully controlled by software, hardware, or both (i.e. formation and transmission) and may, for example, be UDP packets. The other packet group includes signaling, Common Equipment Multiplexed (CE-Mux), heartbeat and card-lan messages. They may comprise TCP packets which are software controlled.

[0083] Each PBX cabinet will typically include a switching device, a hardware device that provides a pulse code modulation (PCM), voice and data for the entire PBX system. In one implementation of such device will have an identical number of channels on each side. One side will perform local switching for that particular cabinet (voice devices connected to that cabinet). The other side will be dedicated to perform switching for voice devices located outside the cabinet (not connected directly to the cabinet).

[0084] The PBX may also be equipped with hardware circuitry which includes several Field-Programmable Gallium-Arsenide integrated circuits (FPGA) which provide the certain functionality for IP links. Typically, this includes formatting of the PCM samples from the switching matrix UDP packets and vice-versa; monitoring link performance; and controlling the packet delay buffer. The board may also include several FIFO RAMs for buffering of incoming messages and two dual port RAMs for Packet Delay Variation buffering of incoming PCM data.

[0085] A voice packet includes a sequence of PCM samples that have been captured from the IVD bus and packaged into a UDP/IP packet. Typically, voice packets are limited to having one Medium Access Control (MAC) UDP/IP destination for all samples. The FPGA stores one header that prefixes all outgoing voice packets. The voice header information is written into the PCM Header RAM prior to enabling voice transmission. Transmission of the voice packet is enabled by setting the Voice Device Enable bit in a command register. Packets are sent every 125 microseconds and contain up to 320 PCM samples.

[0086] FIG. 21 illustrates the connections for transmission of voice packets. PBX cabinet 20, which can be either a main or expansion cabinet, is typically able to accommodate up to 320 voice channels. (The maximum number of channels can be configured by the user or the software to include a lesser or greater number of channels.) Daughter board 22 incorporating a FPGA IC is connected to cabinet 20. Each transmitted packet 24 typically contains a maximum of 320 PCM samples. The transmitted packet 26 is forwarded to the network via IP port 28.

[0087] Similarly, PBX cabinet 30, shown in FIG.22, which can be either a main or expansion cabinet incorporates an IP port 38 which receives incoming packet 36. Typically, a FPGA incorporated within board 32 is capable of receiving packets containing, for example, up to 320 PCM samples/channels. The received packet 34 populated with the samples is processed by the FPGA IC so that each byte of the voice frame is re-mapped to unique channels, one for each of the bytes, shown as channels 1, 2...320 in cabinet 30.

C. Performance Measurements

[0088] According to a feature of the invention in data networks, Quality of Service is determined by evaluating at least three parameters: Latency, Packet Loss Rate, and Bandwidth availability. While only three factors are explicitly enumerated here, one of ordinary skill will appreciate that any other parameter relevant to network performance may figure into the determination.

[0089] Latency is a measurement of the time that it takes a given packet to pass between two points in the network. Factors that may affect latency in a network include, for example, the type and number of switches, type and number of routers, retransmission, distance traveled, network congestion, and link bandwidth. Packet Loss Rate is related to the number of packets that become dropped from the network as a consequence of lack of network resources. One of the factors that may affect the Packet Loss Rate is the packet dropping mechanism used by the router, such as Random Early Drop. It is expressed as a ratio or percentage, as will be more fully described hereinafter. Bandwidth Availability is governed by both Latency and Packet Loss Rate.

[0090] In order to understand the measurement methodology for QoS system requirements, the parameters to be measured and the interpretation of these measurements will next be described.

[0091] Considering, as an example, a system that would provide voice quality in an IP LAN, the following requirements would have to be met:

Network Requirements:

[0092]

Packet Loss Rate of less than 1%.
One way trip time for a packet of 3.75 millisecond.
100 Base-T Full duplex LAN connectivity.

System Requirements:

[0093] Voice Packets:

Rate: 8000 packets/second; and
Packet Width: 320 bytes (one channel per byte, using the G.711 standard).

[0094] Call Set-up and Call Terminating Signalling Packets:

Rate: 250/sec; and
Width: 40 bytes.

[0095] Common Equipment-MUX (CE-MUX) Packets:

Frequency: 10/second; and
Width: 500 bytes.

Given the above system parameters, the required bandwidth, in Mbps, would be 29.25 Mbps, per port.

[0096] This amount represents the bandwidth required for one way traffic. Multiple ports can be assigned on the main cabinet, each communicating with a single expansion cabinet, thereby increasing the available capacity.

[0097] Several ways may be employed to obtain QoS parameters from the IP network application layer. A dedicated client server model (TCP or UDP) can be set up to generate traffic. The client sends a packet and waits for the reply. The server will redirect the same packet upon reception, or send different packets. Implementation is via either synchronous or asynchronous communication modes. In the synchronous mode, the client transmits packets which may contain the system timestamp as well as a counter in its packet payload. In this case, transmission and reception are independent of each other. With asynchronous implementation, the client awaits the reply prior to transmitting the next packet. In this case, a timestamp may or may not be included within the payload.

[0098] Another way to monitor LAN QoS is to use the Internet Control Message Protocol (ICMP). In this case only the client is needed to control message formation and time of transmission. (Usually, the network server process will be supplied as part of the operating system or by a third-party, to provide an echo for the client.) Both of these techniques have some real-time impact in addition to the traffic overhead added-on in order to perform the measurements.

[0099] According to a feature of the invention hardware systems are employed to perform measurements using certain parameters associated with voice packets, resulting in more accurate measurements, while avoiding the above-noted shortcomings.

[0100] Packet Loss Counter (PLC). One way of implementing a Packet Loss Counter may be via a hardware register, as shown in FIG. 23a. Each voice packet is labelled (within its payload) with a sequence number. The receiving end monitors the sequence of packets and as each packet is received when a break in sequence of the arriving packets occurs, the counter is incremented by one digit. A number of packets 47a-c, 49a-c, 5 la-c forming data streams 46, 48, 50 are shown entering a plurality of IP ports 41, 43, 45, respectively. When a packet arrives out of sequence, e.g., a sequence such as {1, 3,} (corresponding to packets 47a, 47b, 47c), the counter is incremented by 1. A sequence such as {1, 6, 7} (corresponding to packets 49a, 49b, 49c) results in incrementing the counter by 1, since packet numbers 2, 3, 4 and 5 are missing from the data stream. A sequence such as {1, 3, 2} (corresponding to packets 51a, 51b, 51c) will result in the counter being incremented by 2, since packet #2 arrives out of sequence (after packet #3). Thus, the value on the counter is an indicator of the degree of packet loss.

[0101] FIG. 23b depicts an alternative hardware implementation of a Packet Loss Counter implementation showing data stream 52, including representative packets 53a, 53b and 53c (numbered #1, #2 ... #7000). Using the total number of packet expected to arrive per second (e.g., 8000) as a reference, when each packet arrives (a counter will be incremented until the end of time period (second) here shown as 7000), the balance of 1000 comprising the packets that did not arrive at the port within the given time frame represents the number of packets lost. This measurement may be done at short intervals (e.g., every second). The counter is then reset to the reference number (e.g. 8000). In FIG. 23b which shows the packets traveling as a function of time, the packet loss counter will therefor read 1000 after the first second.

[0102] When the system detects the packet loss counter being incremented repeatedly over a number of time intervals (as in the first mentioned implementation) or more than zero (as in the second mentioned implementation), the inference is that the network is congested. As a result, one or more bandwidth optimization techniques are implemented, according to certain inventive features to reduce the size of the voice packet. An alternative implementation is to use software to perform packet loss measurement TCP/UDP/ICMP-generated traffic.

[0103] Latency. Latency is also an indicator that the network has become congested. One way of recording the round trip time required for voice packets to transit a network is to use a hardware register. Referring to FIG.

24, source 500 marks packet 502 as #1 (Step 1) prior to sending it and also starts timer 504. When the destination machine 506 receives packet 502 (Step 2), it complements the value that will be transmitted on the next packet as packet #2 (508) back to the source (Step 3). Upon the arrival of the #2-marked packet (Step 4), the timer stops and the time difference is stored in the trip register. Such marking is done within the payload of the respective voice packets.

[0104] An alternative implementation is to use software to perform the round trip time measurement using TCP/UDP/ICMP-generated traffic.

Packet/Cell Delay Variation Overflow and Underflow.

[0105] Underflows and/or overflows of the memory buffer (PDV Buffer) result in a change in one or both memory buffer pointers (read/write pointers). Half the buffer memory size is changed spacing between the pointers. Logging this count is done by hardware register record the number of underflow and overflow events. These counters can be used to determine the stte of the network. Underflow occurs when packets arrive slower than the ability of the system to process them. On the other hand, when voice packets arrive from the network faster than the system processes them, overflow occurs resulting in overwriting the previously received packets and consequently resulting in loss of data.

Bandwidth.

[0106] A software module provides measurement of bandwidth. One way of performing this measurement is to sum the total length of arrived packets per second minus the number of packets lost (obtained from the packet loss counter). All the transmitted and received packets are periodic. Another alternative to use TCP/UDP/ICMP to record the round trip time to generate packets of different sizes and to record their round trip time.

[0107] Using the parameters measured according to the above, software consistent with the invention is able to adapt the system to the behavior of the network depending on the measured values. In addition, the user may be provided notice about network behavior and voice quality after such adaptation via a terminal display, a printer or a voice message.

System Reaction

[0108] Based on the measurements described above obtained from the packet loss counter, packet delay variation overflow and underflow and bandwidth measurements. The system will react by taking one or two actions, namely starting of bandwidth optimization and/or changing PDV Buffer size.

Bandwidth Optimization

[0109] A number of mechanisms can be employed consistent with the present invention to optimize the transmission bandwidth. These include: Static Bandwidth Optimization, Adaptive Bandwidth Optimization and Combined Mode. With the exception of the Static Bandwidth Optimization method, bandwidth optimization is performed by reconfiguring the switching matrix residing on the main cabinet and on the expansion cabinet. In addition, a table containing the updates of the recent configuration of the switching matrix will be maintained on both cabinets. Issuing the commands to reconfigure the switching matrix can be reserved to the main cabinet and synchronization of the table will follow. The new maximum number of channels is required to be set or both the main and expansion cabinets based on the new switching matrix configuration which may result in a lesser number of channels to be transmitted by both the main and expansion cabinets. This can be achieved by getting a new value through the FPGA.

1. Static Bandwidth Optimization:

[0110] This feature involves the user configuring a value which limits the maximum number of channels transmitted (by, e.g., blocking or disabling several voice channels exceeding such limit), when the software detects problems such as packet loss. As previously described, the maximum number of channels to be transmitted is typically on the order of 320. If the packet loss counter is incremented in several consecutive time windows, the software will instruct the FPGA to decrement this value, thus reducing the number of voice channels and appropriately notify the user that bandwidth has been reduced.

2. Adaptive Bandwidth Optimization:

[0111] This feature may be implemented via several techniques: Empty Slot Elimination, Idle Channel Elimination, Idle Card Elimination and Priority Based Card Elimination:

a. Empty Slot Elimination:

[0112] Typically, each slot is represented by 32 bytes (32 channels on the IP packet, where the slot number is mapped to the location of these channels in which the first slot channels will be followed by the second slot channels). The QoS software can recognize the inserted cards in the expansion cabinet. A lookup table eliminates empty slots and includes only channels which correspond to physically inserted cards in the voice packet by realigning channels, either by moving them from the end of the packet to an empty slot location, or by shifting the channels by the value of the empty slots. As an example, if card 1 is present, card 2 is absent,

and card 3 is present, channels associated with card 4 may be mapped into the slot #2 location in the IP packet, via software implementation.

b. Idle Channel Elimination:

[0113] The software monitors active (busy) channels in which communications between the main cabinet and a voice device on the remote cabinets is established based on the information provided by signalling (since the main cabinet performs all switching). The software re-maps the active channels from the end of the voice packet to the first available idle one (e.g., channel number 320 can be remapped as number 30).

c. Idle Card Elimination:

[0114] As the software monitors the number of active channels on a given card, if all channels are idle for that card, this will be treated as if it were an empty slot (i.e., the card will be eliminated, as in the case of empty slot elimination). Once there is a request for a call setup from (or for) an eliminated card, that card (all or a portion) becomes active and all the channels for that card will be allocated on the packet.

[0115] Referring now to FIG. 25a, there is shown a technique for Idle Card Elimination according to a feature of the invention.

[0116] A packet 180, here shown as comprising three cards, 186, 188, 190, also includes an IP header 182 and a UDP header 184. Each card has 32 channels assigned to it. Certain channels are active (designated in the Figure as "A") and others are inactive or idle (designated as "I"). In the example shown, all of the channels in the second card 188 are idle. With the Idle Card Elimination feature as shown in FIG. 25b, the channels associated with the second card are eliminated, the channels associated with the third card, 190, are mapped as channels associated with card #2 and the system recognizes that packet 1800, containing header information 1820, 1840 now contains two cards, 1860 and 1880, each having at least some channels active. The bandwidth is thus optimized by reducing the number of channels associated with cards in the transmitted packet. This can be achieved by searching the switching matrix status table described earlier for a group of channels collocated with each other with an starting index matching the index of the first channel on a given card.

[0117] For example, if a cabinet contains cards 1, 2 and 3, each card being associated with 32 channels on the IP packet, the search would start at channel 1 and look at the next 32 channels to check whether all 32 channels are idle. If not, the same process will be repeated, starting at channel 33. If there is a match, i.e., all 32 channels are idle, these channels will be eliminated from the IP packet.

[0118] If a signalling message from a voice device located on the expansion cabinet requests a connection or channel that is not allocated within the IP packet, the main cabinet will search for a card corresponding with that voice device requesting the connection. If the card is physically inserted, all of the corresponding channels will be reinserted within the IP packet. (All or a partial number of the channels may be reinserted again.)

[0119] The search is time dependent, i.e., the search can be configured to be performed periodically or within varying time window frames.

d. Priority Based Card Elimination:

[0120] The user assigns priority for each card present in a cabinet.

[0121] When a priority based card elimination process starts, the card will be eliminated from the IP packet, based on its assigned priority.

[0122] Referring now to FIG. 26a, there is shown a technique for card priority assignment according to a feature of the invention.

[0123] A packet 190, here shown as comprising three cards, 196, 198, 200, also includes an IP header 192 and a UDP header 194. Each card has 32 channels assigned to it. In this example, the system is configured to assign the highest priority to the second card 198, and the lowest priority to the first card, 196. When network conditions are such that bandwidth optimization needs to be enabled, the system drops the card having the lowest priority. In this particular example, channels associated with card 196 (having the lowest priority) are dropped and channels associated with cards 198 and 200 are shifted in position. As shown in FIG 19b, channels associated with card 198 are then remapped as the first card, 1960, and channels associated with the third card are remapped as if they were associated with the second card, 2000.

[0124] This process may be continued based on the next lower priority of the remaining cards. Thus, the channel associated with the third card 2000 in FIG. 26b was, for example, assigned the lowest priority and the channel associated with the second card 1960, the highest. FIG. 26c shows the resulting configuration after implementing priority based bandwidth optimization. The channels associated with a single card 1904 (corresponding to card 1960), 198, remains in the packet. Again, the number of channels associated with cards in the transmitted packet has been reduced.

[0125] This can be implemented by maintaining a table that contains the priority assignment for each inserted card. Once bandwidth reduction is required, a search for the lowest priority is conducted in the table and a corresponding channel associated with the identified card (i.e., the card with the lowest priority) will be eliminated from the IP packet. This elimination is done by reconfiguring the switching matrix and updating the table.

3. Combined Mode:

[0126] A combination of both Static and Adaptive bandwidth optimization modes may also be enabled. In this mode, the user configures the maximum number of channels to transmit, along with Empty Slot Elimination, Idle Channel Elimination, Idle Elimination, Priority Based Card Elimination, or any combination thereof.

PDV Buffer Size

[0127] The Packet Delay Variation (PDV) buffer is used to buffer the packets for a certain amount of time, pending their ability to be processed. The PDV buffer length in milliseconds sets the amount of time the packets can "wait" in the buffer. If the PDV buffer size is too large, the resulting delay before the packet can be processed will also be large. On the other hand, if the buffer is small, there is a greater chance that the packet may be overwritten, resulting in a loss of data.

[0128] Overflows and/or underflows are indicators that network has become degraded, resulting in lowered voice quality. To reduce the effect of such degradation, the size of the buffer can be either increased or decreased, depending on the event. Software monitors the buffer through overflow and underflow counters and adjusts the buffer accordingly. In addition, software provides the user the capability to set the size of the buffer manually.

Startup mode:

[0129] One strategy for system startup mode would be the utilization of QoS parameters to measure the bandwidth. The number of transmission channels is increased incrementally until full system capacity is obtained. Also, the PDV buffer size is set to a default valve. Based on information obtained from the Underflow/Overflow counters, the buffer size may be adjusted accordingly.

[0130] Based on another strategy, the System may start up by transmitting the maximum number of channels within the voice packet and based on measurements of QoS parameters, the number of channels may be reduced accordingly.

Software Design Methodology

Parameter Measurement Techniques

[0131] The measurements are calculated for presentation to the user upon his or her request to be stored for later analysis of system behavior.

Packet Loss Rate:

[0132] Regardless of the type of hardware used for implementing the PLC, the following assumptions are made (by way of example only, and are not intended to be limiting in any way). First: on a low traffic network, the Packet Loss Counter (PLC_t) maps, one-to-one, the number of packets lost. Second: that the packets will not be arriving out of order (i.e. all packets will follow the same path from source to destination). Third: 8000 voice packets are transmitted per second. At a given time, the packet loss rate (PL_t) is:

$$\frac{PL_t = 100 \times PLC_t}{8000 \times \Delta_t}$$

where Δ_t is the interval between the current and previous measurement, in seconds.

[0133] Provided the second PLC hardware implementation is used (i.e. measuring the number of packets received, as shown in FIG. 23b), the measurement will be performed every second. Consequently, $\Delta_t = 1$. If the first PLC implementation is used, either a fixed or changing time window can be used to read the hardware register for obtaining the measurement.

[0134] An alternative way to obtain these measurements is via software implementation using TCP/UDP/ICMP-generated traffic. The packet loss, ρ , is computed from the ratio of the number of packets received, *R*, with respect to the number of packets transmitted, *T*,

$$\frac{R}{T}$$

and the percentage is:

$$PL=[(1-\rho)x100]/\Delta_t.$$

where Δ_t is the time window size for this measurement which can be either a fixed or varying window.

[0135] Accuracy of these measurements is dependent on the volume of the traffic generated over a period of time.

[0136] Latency: Assuming by way of example only that incoming and outgoing packets follow the same path, i.e. the network latency is the same in both directions, at a given time, t, the one way latency (L_t) introduced by the network is:

$$L_t = \frac{rtt_t}{2} - \text{(processing time)}$$

where rtt_t is the round trip time for the packet transmission. For hardware implementation of round trip time measurement, the processing time is negligible, and thus assumed to be zero. An alternative way to obtain these measurements is a software implementation using TCP/UDP/ICMP-generated traffic. For software implementation, accuracy of these measurements is de-

pendent on the volume of the traffic generated over time, as well as processing time.

[0137] Since voice packets are transmitted and received periodically, a more accurate measurement can be obtained by calculating the time difference between the arrival of two consecutive packets.

Packet Delay Variation:

[0138] Since streaming of voice packets are timely-dependent, this parameter may be used to monitor voice quality.

[0139] If a hardware implementation is used, an indication of packet delay variation is any increment of overflow and/or underflow in the packet delay variation register. Polling of this register can be done via either a fixed or varying time window.

[0140] The Packet Delay Variation may be defined as the difference between the average (moving/changing/incrementing history window) arrival times and the arrival times of the latest packet. Consequently, an alternative way to obtain these measurements is a software implementation using TCP/UDP/ICMP-generated traffic. The minimum, maximum and average values of the packet arrival times are recorded for a specific period of time in a file, memory or a buffer.

Bandwidth:

[0141] Assuming that outgoing packets will always follow the same path, at a given time, *t*, the bandwidth, BW_t is:

[0142] BW_t= [(sum of size of packets transmitted) - size of packet loss)]/ Δ_t

where Δ_t is the duration of the measurement interval in seconds.

[0143] An alternative way to obtain bandwidth measurements is to use TCP/UDP/ICMP-generated traffic.

[0144] For simplicity, and to minimize the add-on traffic as well as to reduce the computational overhead on the CPU, two TCP/UDP/ICMP packets of different sizes are sent periodically. These messages are labelled as small and large packets (depending on their respective sizes). After the reception of both echo replies, the difference Δ_τ between the round trip times, *rtt*, of the large and small packets is computed, as follows:

$$\Delta_\tau = rtt_\lambda - rtt_s$$

where rtt_l and rtt_s are the round trip times for the large and small packets, respectively. Another parameter used to compute *BW* is the difference in packet lengths:

$$\Delta_\lambda = L_1 - L_s$$

where L_l is the length of the large packet and L_s is the length of the small packet, in bits. Finally, the throughput is

$$BW = \frac{\Delta_\lambda}{\Delta_\tau}$$

Bandwidth Restoration

[0145] The software will monitor the availability of bandwidths measured as described in the previous section and the PLC for a period of time. Once a repetitive reading from the PLC indicates that no additional packets have been lost, bandwidth optimization mechanisms may then be reversed gradually. Bandwidth is then monitored continually to determine if any degradation has occurred. The increment is done gradually up to the maximum number of channels available on the system. The time window used to monitor the PLC and bandwidth measurements can be of a fixed or changing size.

PDV Buffer Size Restoration

[0146] As software will monitor the PDV Underflow/Overflow counters for a period of time, when it detects that there is no change in either counter, software will reduce the size of the buffer gradually and continue monitoring under either of these counters increments.

User Interface

[0147] The QoS monitoring functionality is interpreted as rating the Quality of Service of the data network based on predefined thresholds. Ratings and average values are displayed on the user terminal and also are stored, for example, in a fixed-size log file. In addition, the software permits changing and configuring several parameters, such as PDV buffer size, maximum number of channel and thresholds.

[0148] Control of QoS monitoring can be maintained on either the main or the expansion cabinet. If any QoS parameter goes below a predefined threshold level, appropriate warning messages are generated and communicated to the user on a display, printer or via a messaging system, such as a pager. The thresholds used are either default values or user-defined new values.

[0149] The parameters displayed include:

RTD (Round Trip Delay).
Packet errors (Loss).
PDV buffer underflows.
PDV Buffer underflows.

[0150] Examples of rating thresholds and the accompanying respective message displays are as follows:

Round Trip Time Delay (RTD)	
Threshold	Message Displayed
<10 ms	Excellent
<15 ms	Good
<20 ms	Fair
>20 ms	Poor

Packet Loss (% of errors)	
Threshold	Displayed Message
<1%	Excellent
<2%	Good
<3%	Fair
>3%	Poor

[0151] Obviously, these thresholds are exemplary only and may be adjusted to suit user requirements. Since multiple ports are available on the main cabinet, the user may specify the port or ports to be monitored. Configuration of each port may be done collectively or independently.

Detailed Architecture

[0152] The QoS monitoring software component may be implemented in several ways. One approach involves dedicating a single task (process) on the main cabinet to poll the hardware registers, and perform the actions. In this case, the task is responsible for monitoring all IP ports available on the cabinet. A second approach is to create a separate task per port. In either case, the task performs similar functionality. Collecting the QoS parameters from the expansion cabinet is done in the same way with the exception that these parameters are sent to the main cabinet to perform actions and display this information to the user.

[0153] The QoS monitoring task is created on the main and the expansion cabinets at start up, and are running all the time. Upon initiating the task on the main cabinet, a message queue is created to accept commands from the user to display the current measurement statistics of the system's behavior. Both tasks then start polling hardware registers using a default fixed or changing time window. The percentage of packet loss is computed, and compared with a predetermined threshold. To ensure the accuracy of the measurements, the status of the link between the two cabinets is checked regularly based on the smallest measurement window obtained from a database file stored on the system computer.

[0154] To maintain consistency, the size of the PDV buffer, measurement time windows, and thresholds for each port is maintained in the database file. This file contains one entry for each Main Cabinet port and one entry for each Expansion Cabinet port.

[0155] All bandwidth optimization mechanisms can start on either end of the network as long as all related information is transmitted to the other end. The user has the flexibility to choose which technique to use.

[0156] The empty slot elimination bandwidth mechanism is based on card detection. The slot number of the inserted cards in the expansion cabinet is obtained. An array of size 10 is created. Its index represents the logical slot number and its value represents the physically inserted slot number (e.g., if cards 1 and 3 are inserted, the array is Slot[1] = 1, Slot[2] = 3, Slot[3] = null). On the main cabinet side generally only the XIVD values are calculated from the array.

[0157] The empty channel elimination bandwidth mechanism is based on monitoring the activity of all channels. This is achieved by creating an array of 320 representing the expansion physical channels and marking the active ones based on the information provided from signalling. A channel can only be marked once. When blocking is introduced, and a new connection request is made for a channel that exceeds the blocking range, the array is searched for a non-active channel and the corresponding array element is marked with the new channel number. For example, if the maximum number of channels is set by the user to be 180, and if channel 200 is requesting connection and element indexed 100 is not marked, channel 200 will be assigned logical channel 100. On the expansion side, the NIVD unit will be the logical value of the newly-assigned channel and the XIVD is the actual unit from the card. In the main cabinet the XIVD unit will be obtained from the array.

[0158] Changing the packet size for any of the optimization techniques implemented involves setting the local FPGA register with the maximum number of channels to transmit and notifying the other side of the new bandwidth so that it can set its FPGA register. This is done either by directly setting the FPGA of the expansion cabinet using the Remote Call Procedure (RPC) protocol or sending a new TCP or UDP message and implementing a server on the expansion cabinet to wait for these types of messages and setting the FPGA with the new values or include this message with other existing messaging systems (e.g., heartbeat, signalling, cardlan).

[0159] Similarly, setting the PDV buffer size, using either RPC or sending the new value to the other side in a message can be used. The difference in this case is that setting is done independently, i.e., changing the buffer size on the main cabinet may not require changing the size of the expansion cabinet. Software implementations comprising features of the present invention may be divided into three processes: Packet Loss Counter, Packet Delay Variation and Bandwidth Optimization.

[0160] Referring to FIG. 27, there is shown a flow

chart depicting a process for measuring the amount of packet loss as an adjunct to enabling bandwidth optimization. A complete packet interval needed to fill the Packet Loss Counter hardware register described earlier is awaited (step 60). Next, the Packet Loss Counter (PLC) is read (step 62). If the PLC reading exceeds a predetermined threshold (expressed as PLC > Thr1) and, if the current PLC reading compared to the previous PLC reading is greater than zero (Δ PLC > 0) (step 64), the PLC flag is incremented by 1 (step 66). Otherwise, the process of waiting for a complete packet interval is repeated (step 60). After the PLC flag is incremented (step 66), the PLC flag reading is compared to a second predetermined threshold (PLC_Flag>thr2, step 68). If the value of the flag exceeds that of the threshold, the network is inferred congested and the program proceeds to enable bandwidth optimization (step 70). Enablement also causes the PLC flag to be reset to zero (step 72) at which point the system and awaits a new complete packet interval (step 60).

[0161] FIG. 28 shows a flow chart for measuring packet delay variation. As previously mentioned, packets arriving faster than the current system set up to process them can result in loss of data. Conversely, packets arriving too slowly may result in gaps in the data, noticeable as pauses during voice conversations.

[0162] A complete packet interval needed to fill the Packet Delay Variation (PDV) hardware buffer, described earlier, is awaited (step 70). The number of events of overflow and underflow in the PDV buffer is then read (step 72) and if there is any overflow (OverFlow>0, step 74), value of the overflow variable is incremented (step 76). The PDV_OF value is then compared with a predetermined overflow threshold value (PDV_OF>OF_Thr, step 78). If the PDV_OF value exceeds that of OF_Thr, the PDV_OF variable is reset to zero (step 82).

[0163] The PDV overflow threshold has not been exceeded (step 78), a new packet interval time slot is awaited (step 70) and the steps are repeated.

[0164] With continuing reference to FIG. 28, no overflow is detected (step 74) the packet underflow count is compared to zero (step 84). If the count does not exceed zero, a new packet interval branches back to step 70 time slot is awaited. On the other hand, if the underflow count is greater than zero, the underflow variable PDF_UF is incremented (step 86). Program step 88 is a logic step which compares the underflow variable from step 86 to a predetermined underflow threshold (UF_Thr). If PDV_UF is greater than UF_Thr, the buffer size is reduced at step 90 and the PDV_UF variable is reset to zero in step 92. If PDV_UF is less than UF_Thr, at logical step 88, the program branches back to step 70 to await the next packet interval. Upon resetting in step 92, the program also branches back to step 70.

[0165] FIG. 29 illustrates a flow chart showing implementation of bandwidth optimization. An indication from the program that bandwidth optimization is to be implemented, such as the enable bandwidth optimization program command 70 shown in FIG. 27 initiates the process.

[0166] If adaptive bandwidth optimization is not to be enabled, a decision is made whether or not to enable static bandwidth optimization (step 102). If no, a degraded network condition is reported to the user (step 104). If Static BwOpt is enabled (step 102), static bandwidth optimization is enabled (step 108). If adaptive bandwidth optimization is to be enabled (step 100), the program (Adaptive BWOpt enabled).

[0167] Adaptation mechanism systems and methods consistent with the present invention reduce the amount of bandwidth required to transmit voice data in a network. Because transmission is limited to active channels, the bandwidth is utilized in an efficient manner regardless of the number of physical cards present on the network.

[0168] It will be seen that the present invention can, for example, be implemented in architecture other than centralized, master/slave configuration. More than one PBX can be provided, such as in a distributed PBX environment with multiple cabinets performing at least one of the function of the centralized master cabinet. Backup cabinets could also be provided to prevent communication disruption in the event of a breakdown of a primary cabinet.

[0169] In addition, the system and method of the present invention could be implemented as part of a Meridian-1 system manufactured by Nortel Networks and include Option 11C cabinets. Also, the foregoing description is based on a client-server architecture.

[0170] Additionally, although aspects of the present invention are described as being stored in memory, one skilled in the art will appreciate that these aspects can also be stored on other types of computer-readable media, such as secondary storage devices, like hard disks, floppy disks, or CD-ROM; a carrier wave from the Internet; or other forms of RAM or ROM.

[0171] Also, the foregoing description is based on a client-server architecture, but those skilled in the art will recognize that a peer-to-peer architecture may be used consistent with the invention. Moreover, although the described implementation includes hardware and software, the invention may be implemented only in hardware or only in software.

Claims

1. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising the steps of:

   identifying a parameter associated with a data packet transported across the network;
   measuring the parameter; and
   enabling optimization of the network bandwidth

when said measured parameter differs from a predetermined value.

2. Apparatus for dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising:

first and second PBX cabinets interconnected in a local area network configuration for sending and receiving data packets;
a register in connection with at least one of said cabinets for storing a value associated with a given packet;
a comparator for comparing said value with a predetermined value; and
an optimization mechanism for adjusting the bandwidth of the network when said measured value differs from a predetermined value.

3. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising as set forth in claim 1, wherein:
said parameter comprises a sequence number associated with the payload portion of said data packet.

4. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising as set forth in claim I, wherein:
said parameter comprises measurement of the difference in arrival times of packets sent across the network and back between a first packet and a second packet.

5. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising as set forth in claim 1, wherein:
said parameter comprises measurement of the difference in arrival times of packets sent across the network and back between the average value of arrival times of a group of packets and a second packet.

6. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising as set forth in claim 3, further comprising the substep of:
storing the sequence numbers of data packets in a register.

7. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising as set forth in claim 6 further comprising the substep of:
storing sequence numbers associated with successive data packets in the register.

8. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising as set forth in claim 7 further comprising the substep of:
monitoring the sequence of sequence numbers associated with successive data packets stored.

9. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising as set forth in claim 8 further comprising the substep of:

incrementing a counter in the register by a count of one when the sequence numbers of successive data packets stored are in sequential order; and
incrementing the counter by a count greater than one when the sequence numbers of successive data packets stored are out of sequential order.

10. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising as set forth in claim 9, further comprising the substep of:
initiating bandwidth optimization when said counter count is incremented by a count greater than one.

11. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising as set forth in claim 10, wherein:
said bandwidth optimization comprises static optimization.

12. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising as set forth in claim 11, wherein:
said static optimization comprises limiting the number of channels available on the network.

13. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising as set forth in claim 10, wherein:
said bandwidth optimization comprises adaptive optimization.

14. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising as set forth in claim 13, wherein:
said adaptive optimization comprises the step of determining which channels are physically represented by cards connected to a PBX network cabinet.

15. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising as set forth in claim 13, wherein:

said adaptive optimization comprises the step of determining whether a channel is inactive and re-mapping an active channel to an available inactive one.

16. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising the steps of:

monitoring the network cards capable of being physically connected to a cabinet;
determining which cards are not present; and
associating channels of a packet with only the cards which are physically present.

17. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising the steps of:

monitoring channels on a network to determine whether any channels are idle; and
mapping active channels from the end of a packet to an available idle channel.

18. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising the steps of:

monitoring channels associated with a plurality of network cards;
determining whether all channels in a given card are idle; and
eliminating a card containing associated channels which are all idle from an Internet Protocol packet.

19. A method of dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising the steps of:

assigning various priorities to a plurality of network cards;
monitoring the status of the network; and
removing a card having the lowest priority in order to optimize the status of the network.

20. Apparatus for dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising:

a parameter identifying mechanism for identifying a parameter associated with a data packet transported across the network;
a parameter measuring device for measuring the parameter; and
an optimization enabling device for optimizing the bandwidth of the network when said measured parameter differs from a predetermined value.

21. Apparatus for dynamically adapting a PBX network-to maintain a Quality of Service level in the network comprising:

a monitoring system which monitors the network cards capable of being physically connected to a cabinet;
the monitoring system determines which cards are not present and associates channels of a packet with only the cards which are physically present.

22. Apparatus for dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising:

monitoring apparatus which monitors channels on a network to determine whether any channels are idle and maps active channels from the end of a packet to an available idle channel.

23. Apparatus for dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising:

monitoring apparatus which monitors channels associated with a plurality of network cards, determines whether all channels in a given card are idle, and eliminates a card containing associated channels which are all idle from an Internet Protocol packet.

24. Apparatus for dynamically adapting a PBX network to maintain a Quality of Service level in the network comprising:

an assigning system which assigns various priorities to a plurality of network cards; and
a monitoring system which monitors the status of the network and removes a card having the lowest priority to thereby optimize the status of the

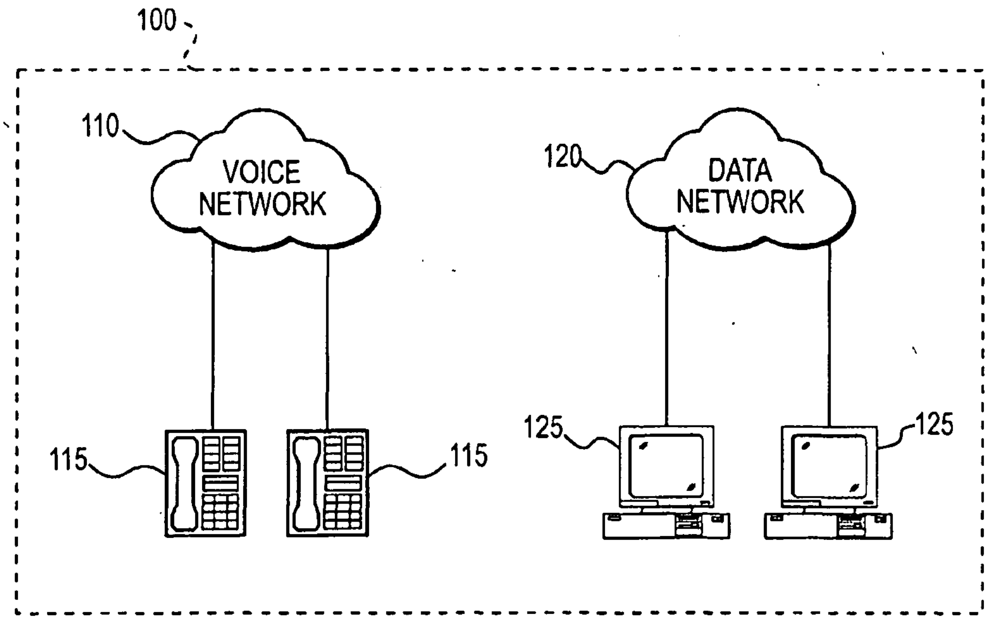

FIG. 1
PRIOR ART

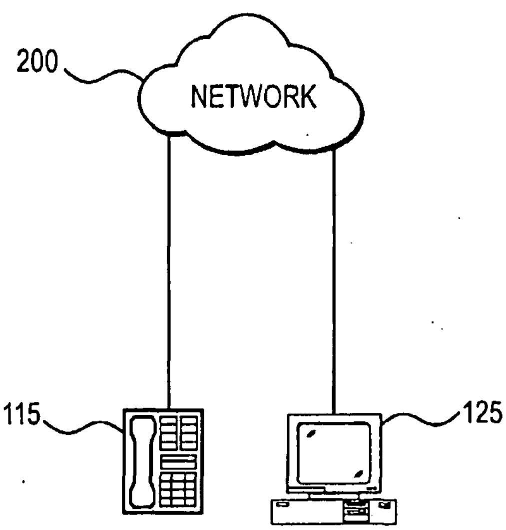

FIG. 2

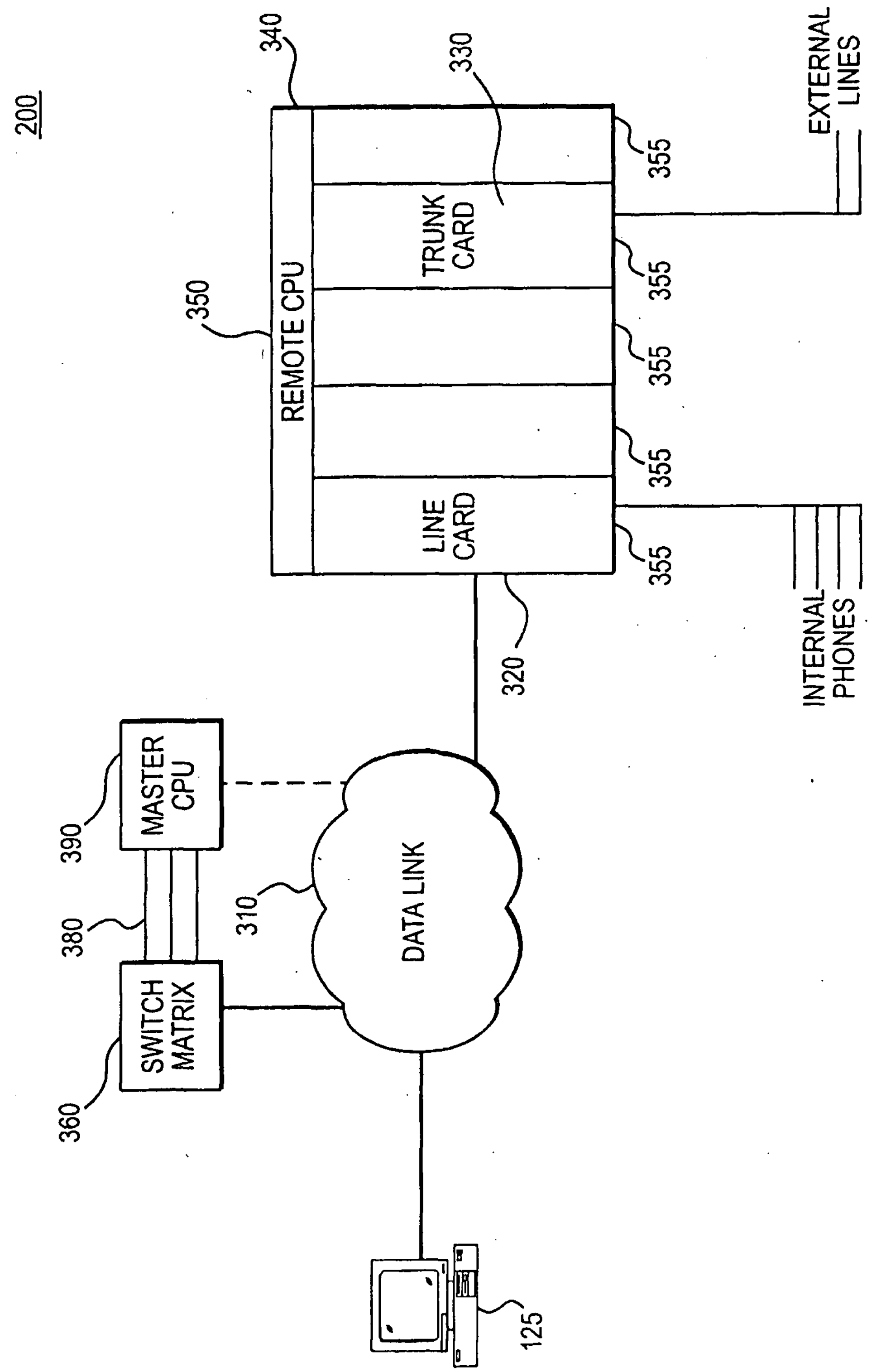
200
SWITCH MATRIX
360
380
MASTER CPU
390
DATA LINK
310
125
320
REMOTE CPU
350
340
LINE CARD
TRUNK CARD
330
355
355
355
355
355
INTERNAL PHONES
EXTERNAL LINES

FIG. 3

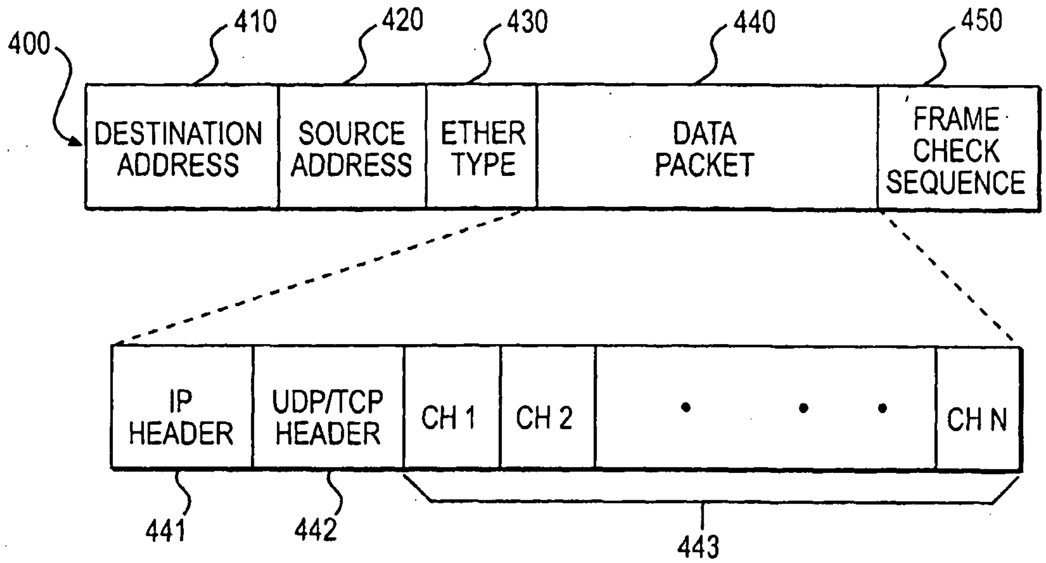
400
410
420
430
440
450
DESTINATION ADDRESS
SOURCE ADDRESS
ETHER TYPE
DATA PACKET
FRAME CHECK SEQUENCE
IP HEADER
UDP/TCP HEADER
CH 1
CH 2
CH N
441
442
443

FIG. 4

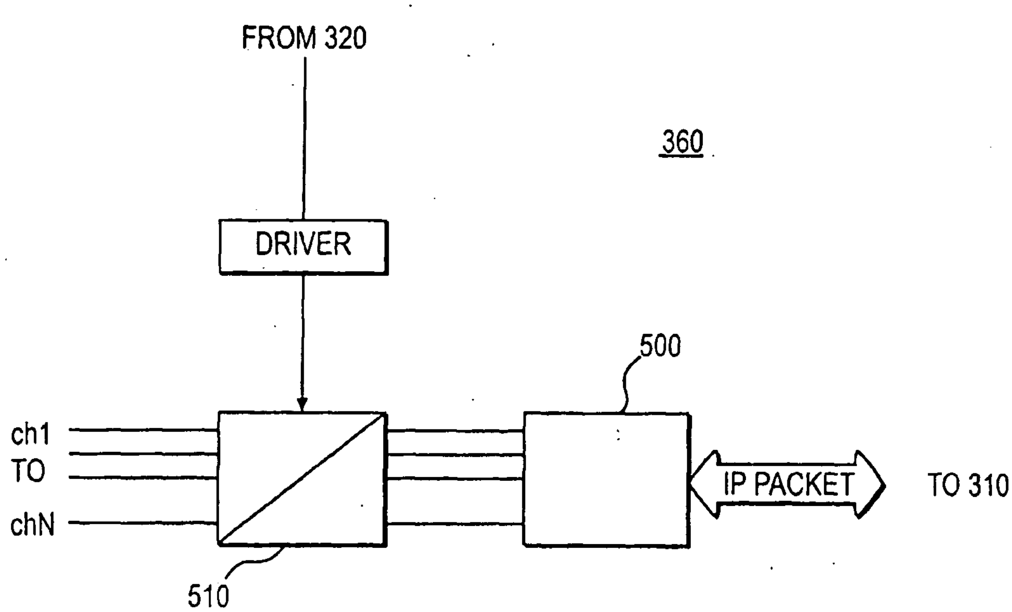
FROM 320
360
DRIVER
500
ch1
TO
chN
IP PACKET
TO 310
510

FIG. 5

600

PACKET POSITION								
1-8	CHANNEL 1	CHANNEL 2	CHANNEL 3	CHANNEL 4	CHANNEL 5	CHANNEL 6	CHANNEL 7	CHANNEL 8
9-16	CHANNEL 9	• • •						
⋮								
1017-N	CH. 1017	• • •						CHANNEL N

FIG. 6

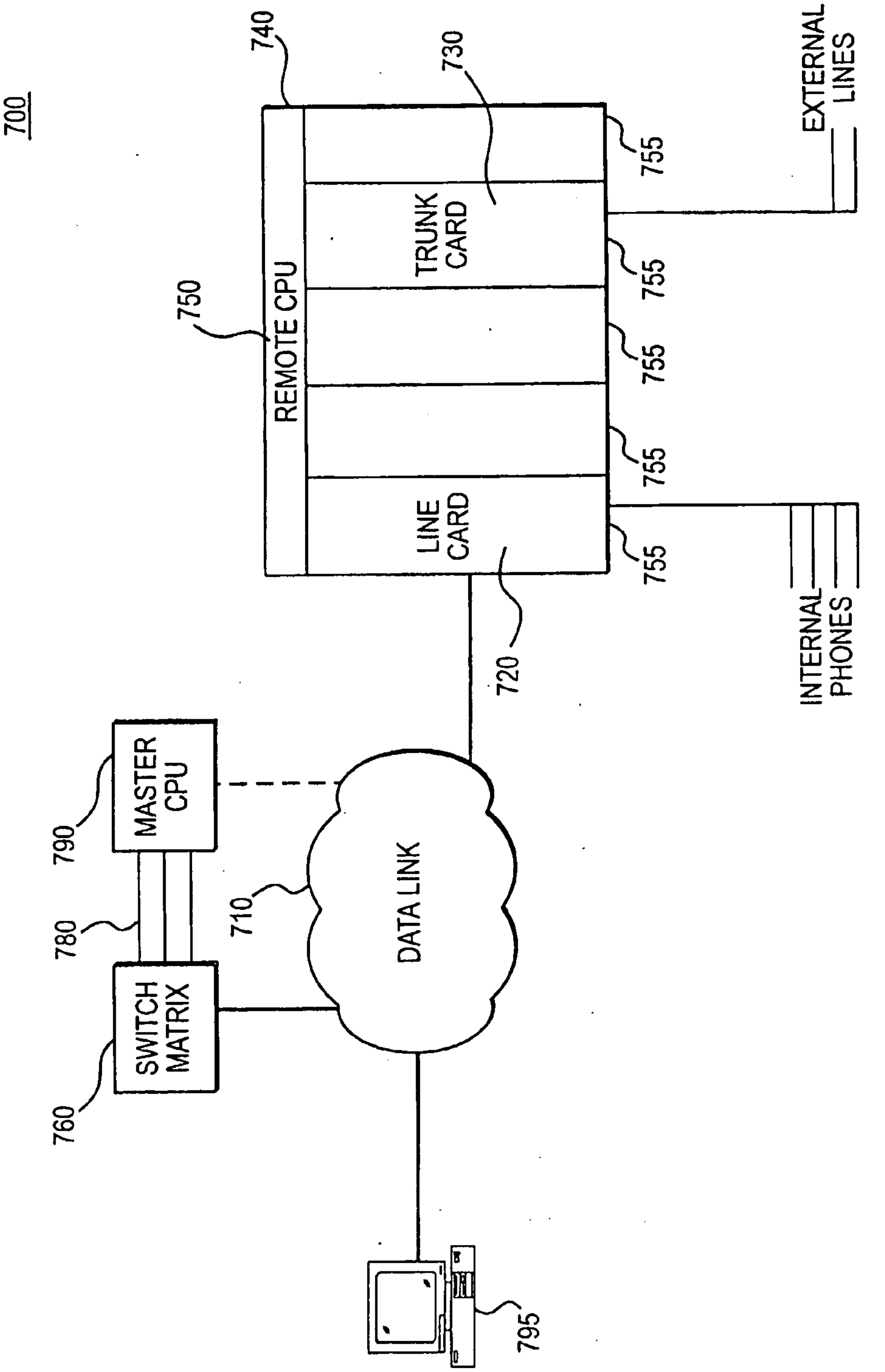
700
740
730
REMOTE CPU
750
TRUNK CARD
755
755
755
755
755
EXTERNAL LINES
LINE CARD
720
INTERNAL PHONES
MASTER CPU
790
780
SWITCH MATRIX
760
DATA LINK
710
795

FIG. 7

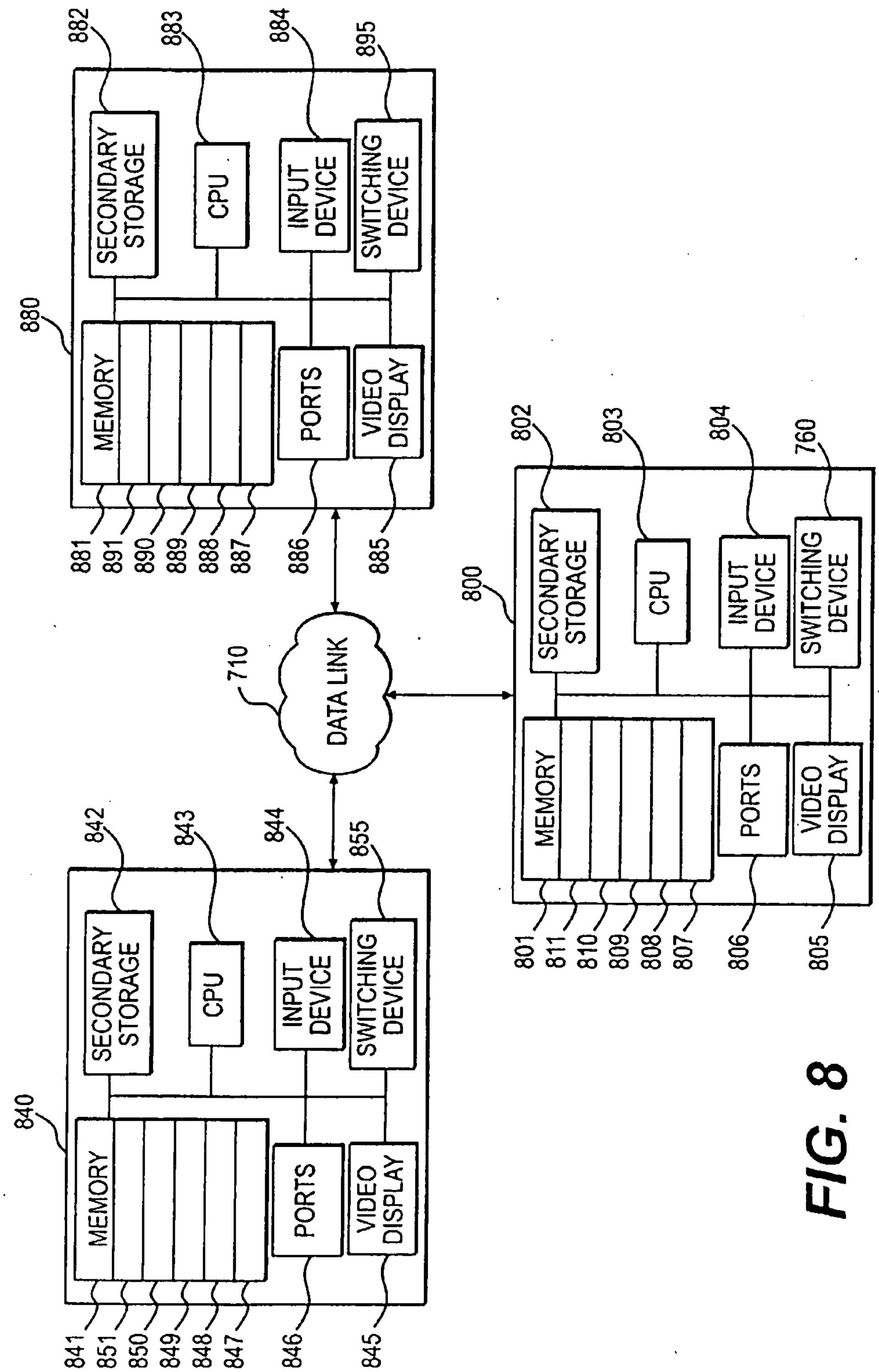
880
MEMORY
SECONDARY STORAGE
CPU
INPUT DEVICE
SWITCHING DEVICE
PORTS
VIDEO DISPLAY
882
883
884
895
881
891
890
889
888
887
886
885
710
DATA LINK
800
MEMORY
SECONDARY STORAGE
CPU
INPUT DEVICE
SWITCHING DEVICE
PORTS
VIDEO DISPLAY
802
803
804
760
801
811
810
809
808
807
806
805
840
MEMORY
SECONDARY STORAGE
CPU
INPUT DEVICE
SWITCHING DEVICE
PORTS
VIDEO DISPLAY
842
843
844
855
841
851
850
849
848
847
846
845

FIG. 8

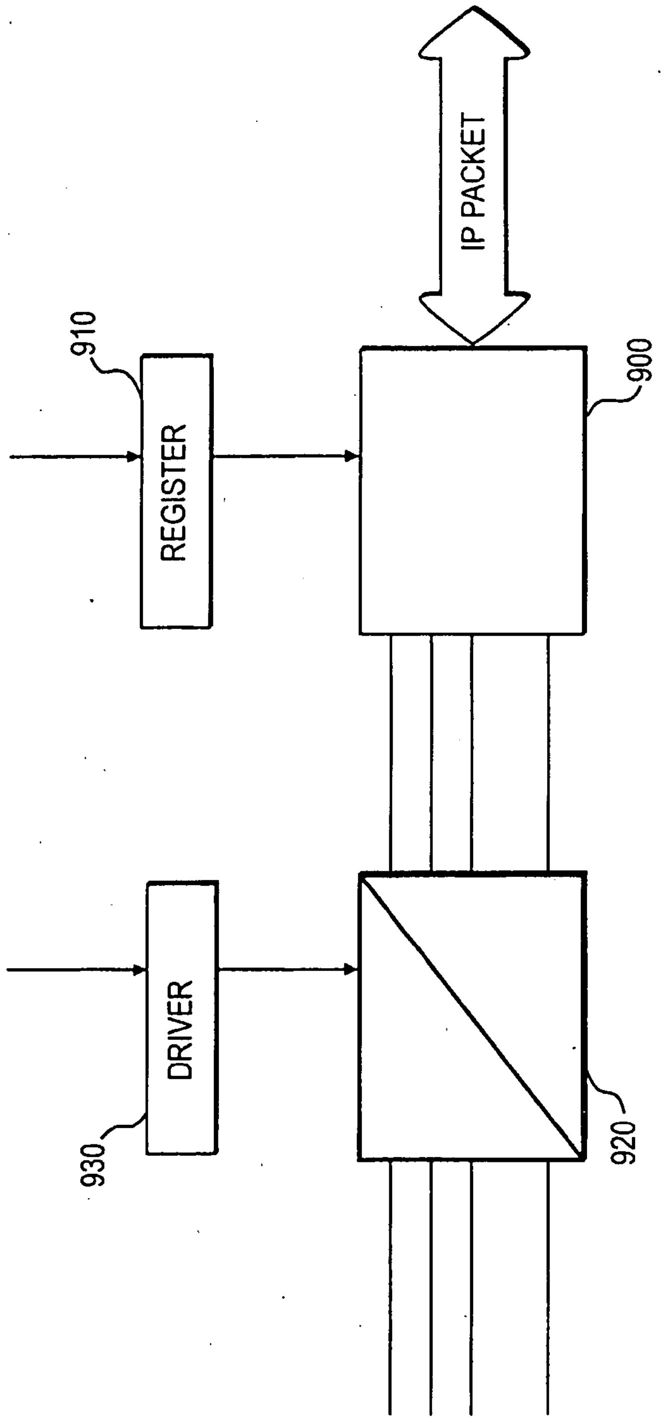

FIG. 9

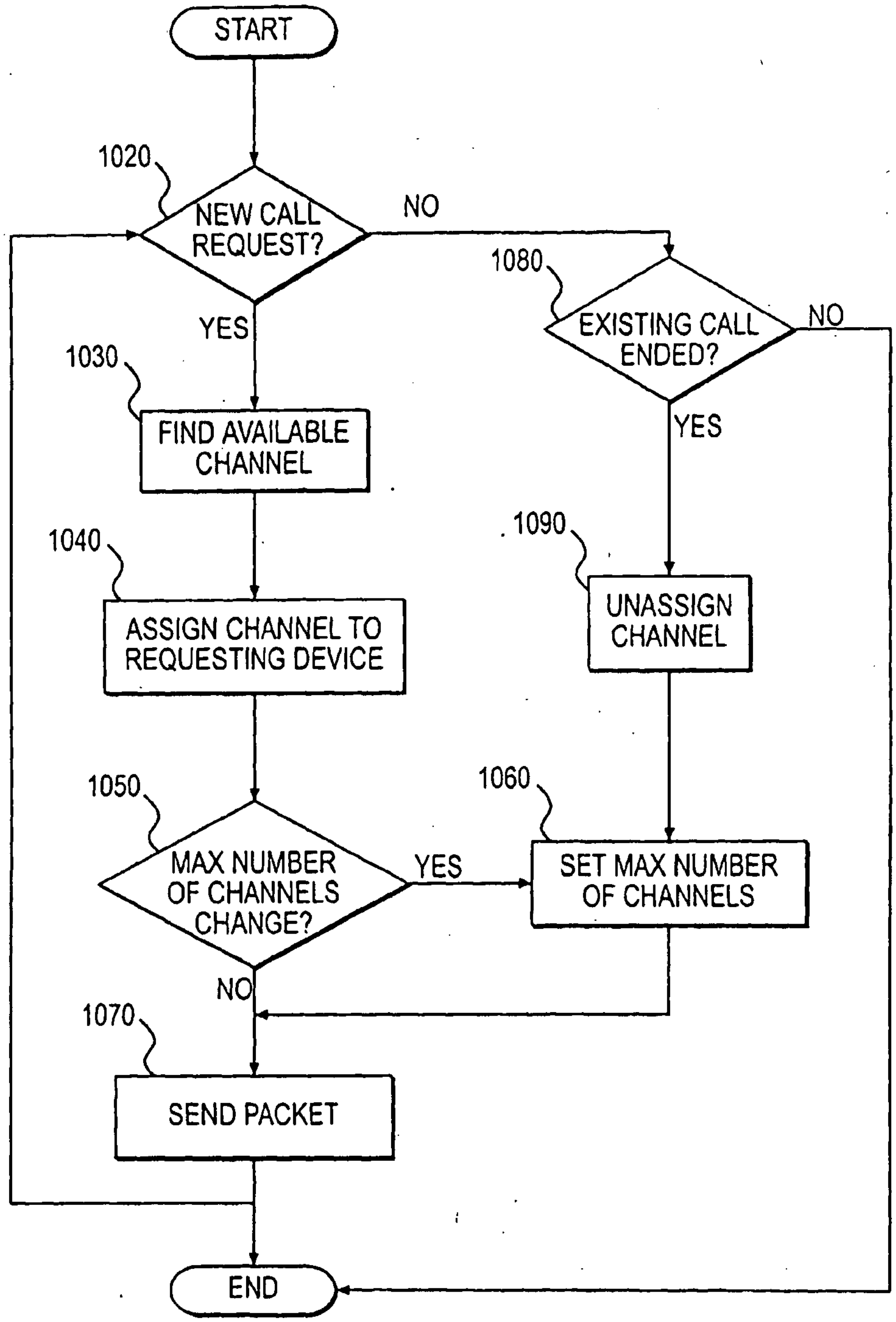
START
1020
NEW CALL REQUEST?
NO
YES
1080
EXISTING CALL ENDED?
NO
YES
1030
FIND AVAILABLE CHANNEL
1040
ASSIGN CHANNEL TO REQUESTING DEVICE
1090
UNASSIGN CHANNEL
1050
MAX NUMBER OF CHANNELS CHANGE?
YES
1060
SET MAX NUMBER OF CHANNELS
NO
1070
SEND PACKET
END

FIG. 10

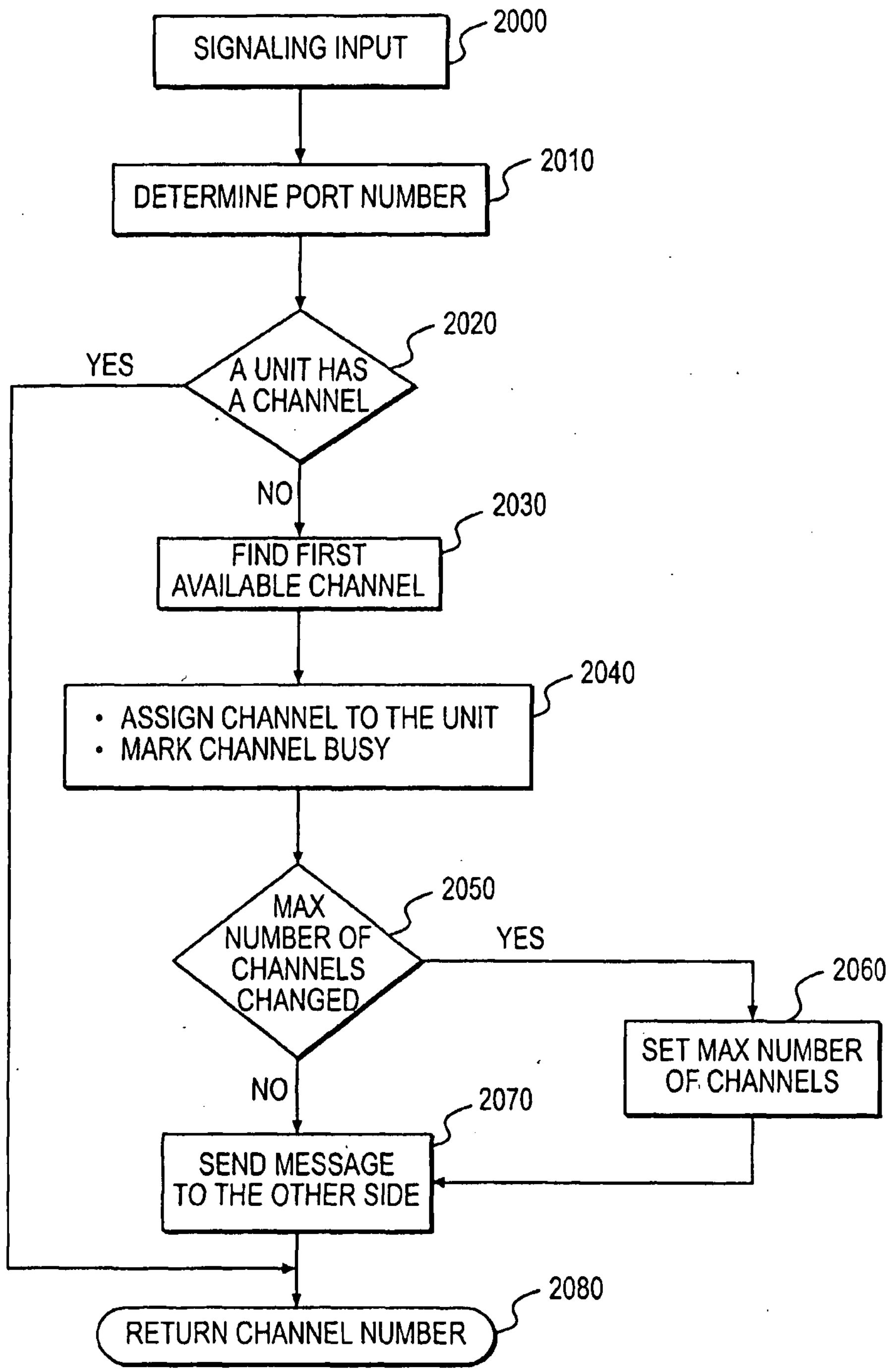
SIGNALING INPUT
2000
DETERMINE PORT NUMBER
2010
A UNIT HAS A CHANNEL
2020
YES
NO
FIND FIRST AVAILABLE CHANNEL
2030
• ASSIGN CHANNEL TO THE UNIT
• MARK CHANNEL BUSY
2040
MAX NUMBER OF CHANNELS CHANGED
2050
YES
NO
SET MAX NUMBER OF CHANNELS
2060
SEND MESSAGE TO THE OTHER SIDE
2070
RETURN CHANNEL NUMBER
2080

FIG. 10a

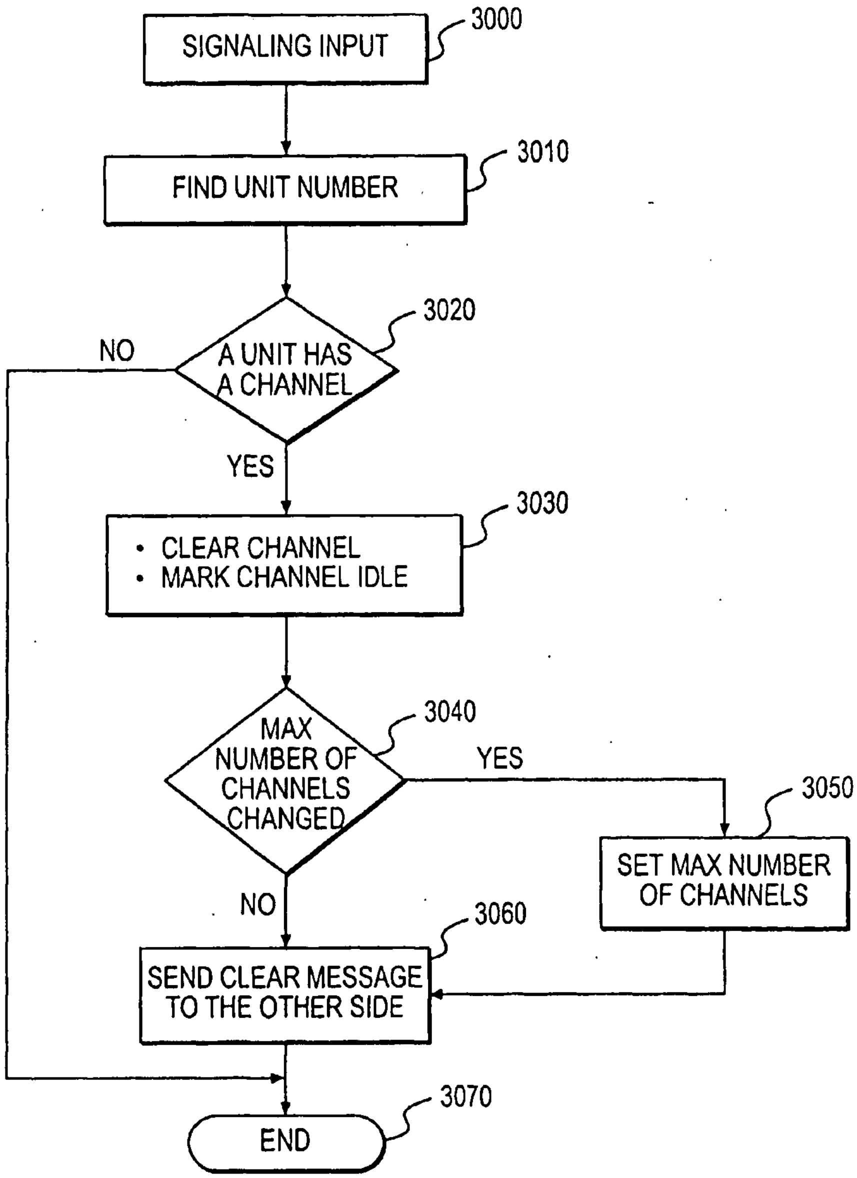
SIGNALING INPUT
3000
FIND UNIT NUMBER
3010
A UNIT HAS A CHANNEL
3020
NO
YES
CLEAR CHANNEL
MARK CHANNEL IDLE
3030
MAX NUMBER OF CHANNELS CHANGED
3040
YES
NO
SET MAX NUMBER OF CHANNELS
3050
SEND CLEAR MESSAGE TO THE OTHER SIDE
3060
END
3070

FIG. 10b

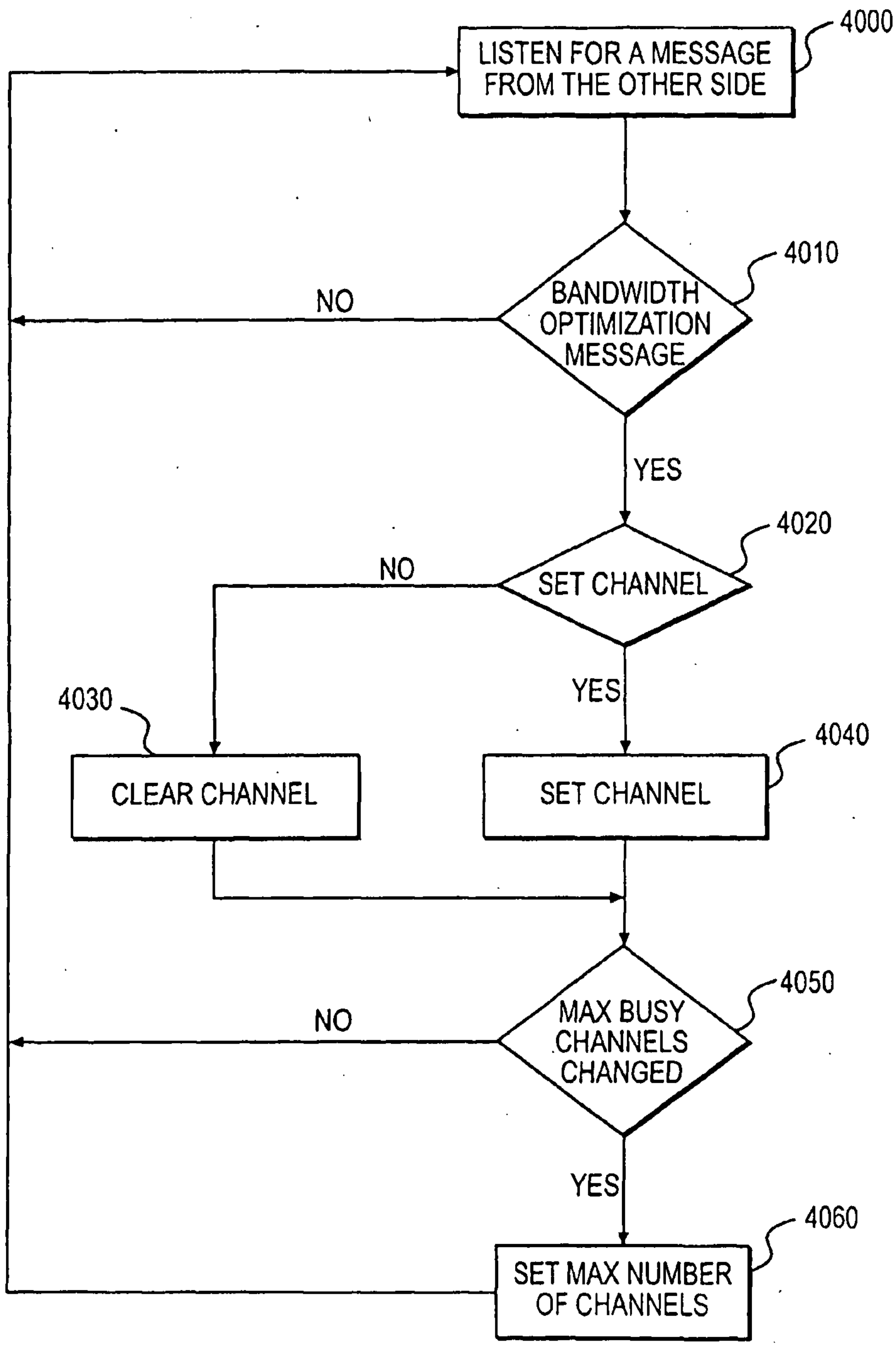
4000
LISTEN FOR A MESSAGE FROM THE OTHER SIDE
4010
BANDWIDTH OPTIMIZATION MESSAGE
NO
YES
4020
SET CHANNEL
NO
YES
4030
CLEAR CHANNEL
4040
SET CHANNEL
4050
MAX BUSY CHANNELS CHANGED
NO
YES
4060
SET MAX NUMBER OF CHANNELS

FIG. 10c

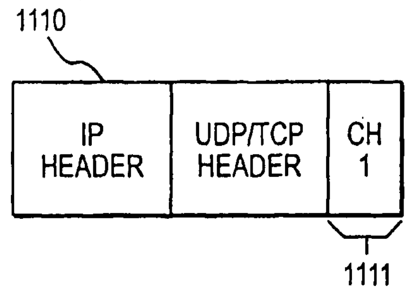

FIG. 11a

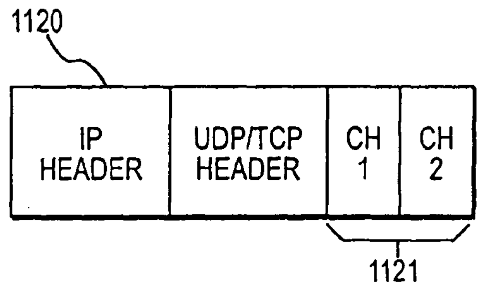

FIG. 11b

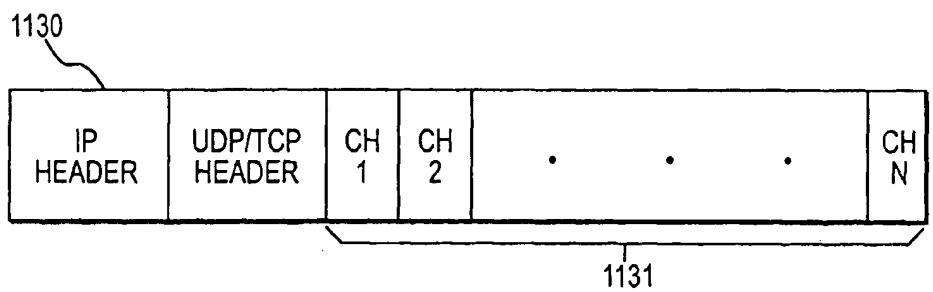

FIG. 11c

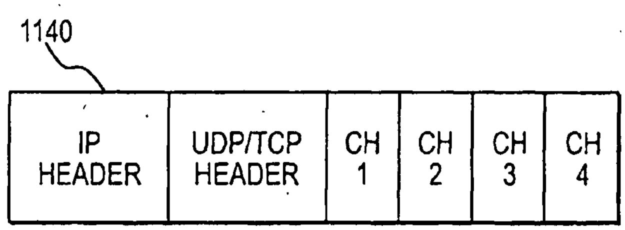

FIG. 11d

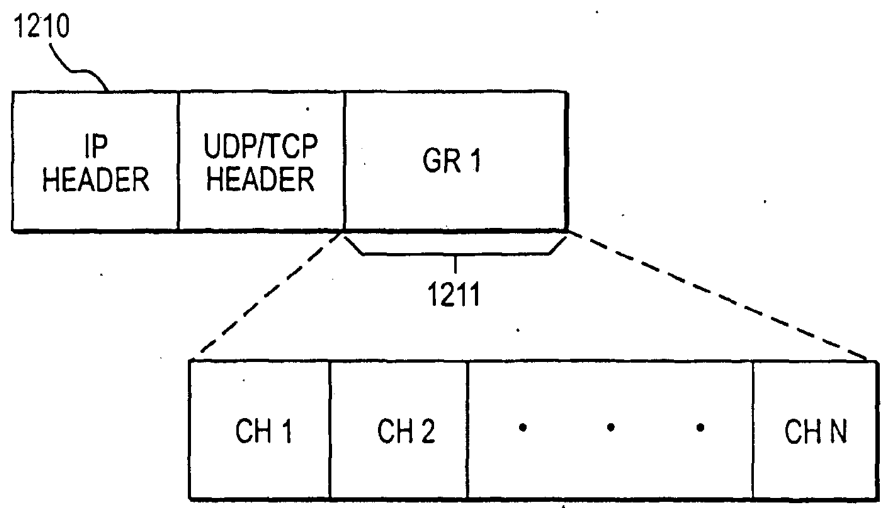

FIG. 12a

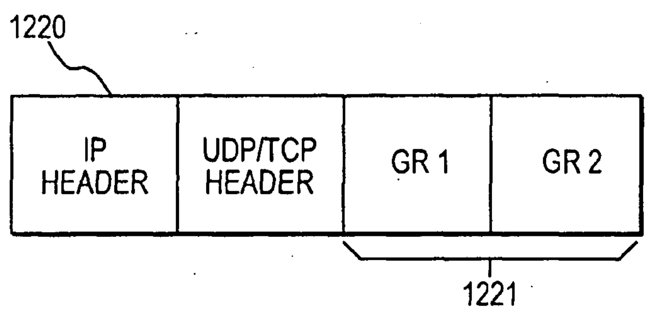

FIG. 12b

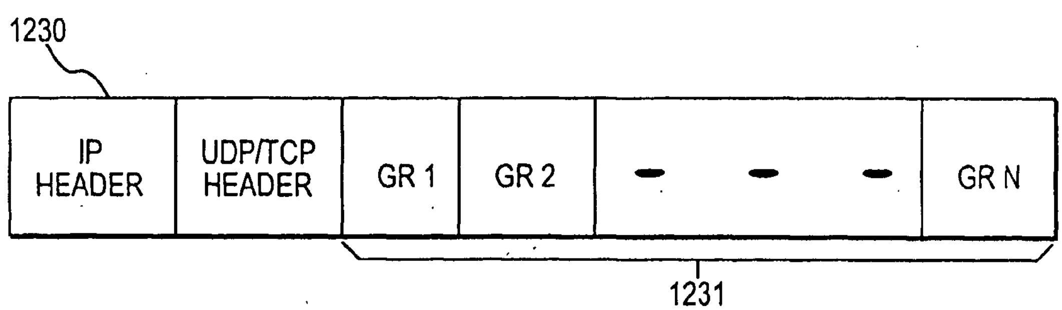

FIG. 12c

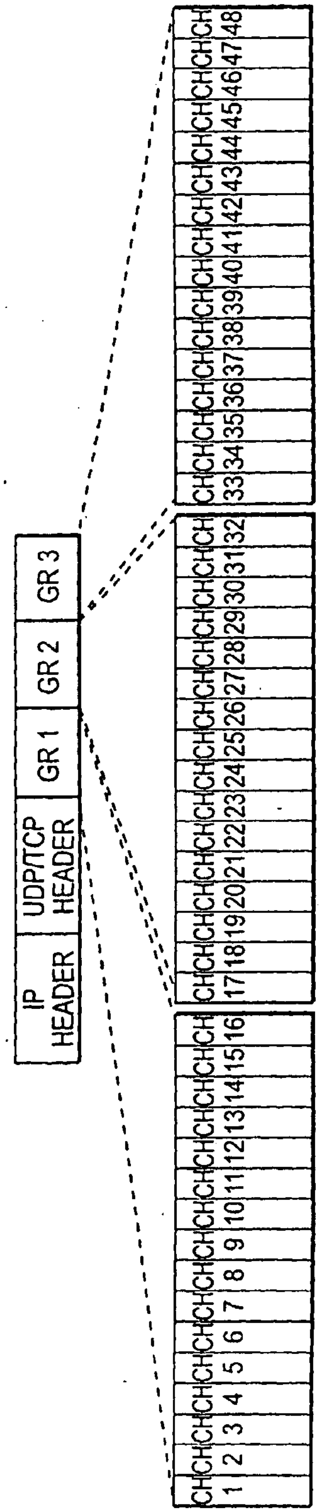
IP HEADER
UDP/TCP HEADER
GR 1
GR 2
GR 3
CH 1
CH 2
CH 3
CH 4
CH 5
CH 6
CH 7
CH 8
CH 9
CH 10
CH 11
CH 12
CH 13
CH 14
CH 15
CH 16
CH 17
CH 18
CH 19
CH 20
CH 21
CH 22
CH 23
CH 24
CH 25
CH 26
CH 27
CH 28
CH 29
CH 30
CH 31
CH 32
CH 33
CH 34
CH 35
CH 36
CH 37
CH 38
CH 39
CH 40
CH 41
CH 42
CH 43
CH 44
CH 45
CH 46
CH 47
CH 48

FIG. 13

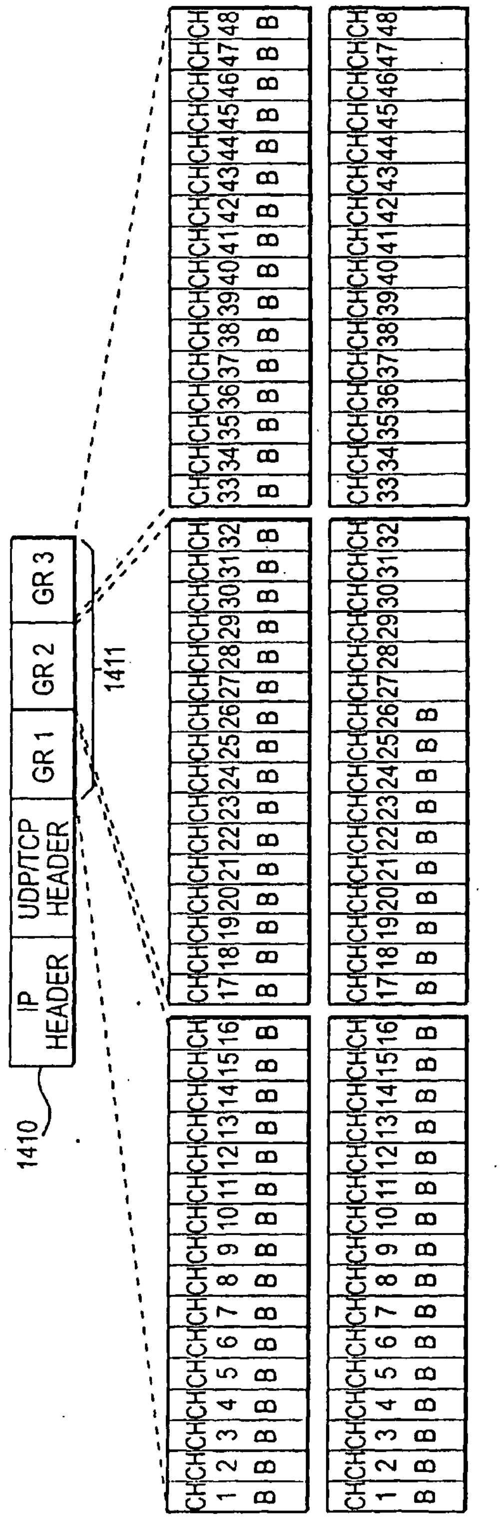

FIG. 14a

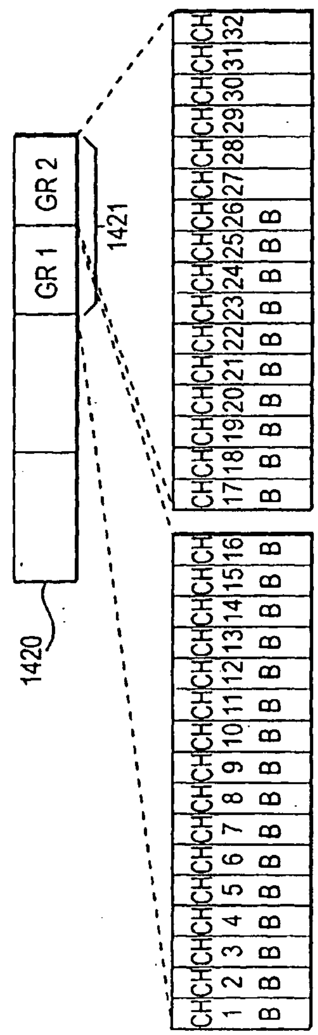

FIG. 14b

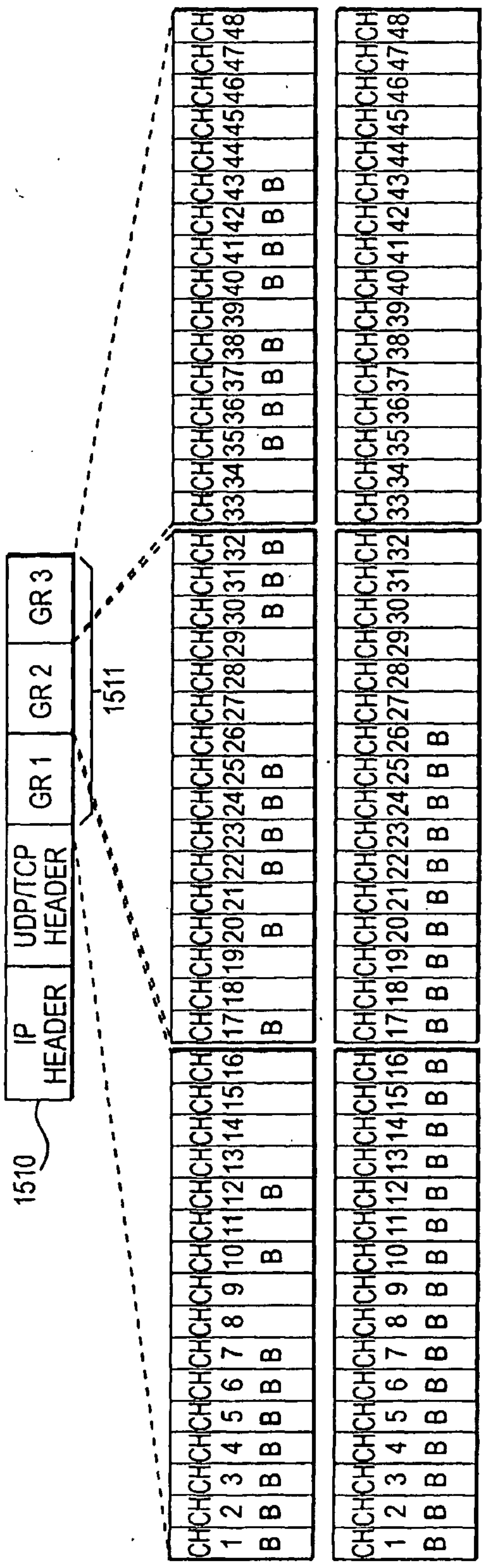
1510
IP HEADER
UDP/TCP HEADER
GR 1
GR 2
GR 3
1511
CH 1
CH 2
CH 3
CH 4
CH 5
CH 6
CH 7
CH 8
CH 9
CH 10
CH 11
CH 12
CH 13
CH 14
CH 15
CH 16
CH 17
CH 18
CH 19
CH 20
CH 21
CH 22
CH 23
CH 24
CH 25
CH 26
CH 27
CH 28
CH 29
CH 30
CH 31
CH 32
CH 33
CH 34
CH 35
CH 36
CH 37
CH 38
CH 39
CH 40
CH 41
CH 42
CH 43
CH 44
CH 45
CH 46
CH 47
CH 48
B

FIG. 15

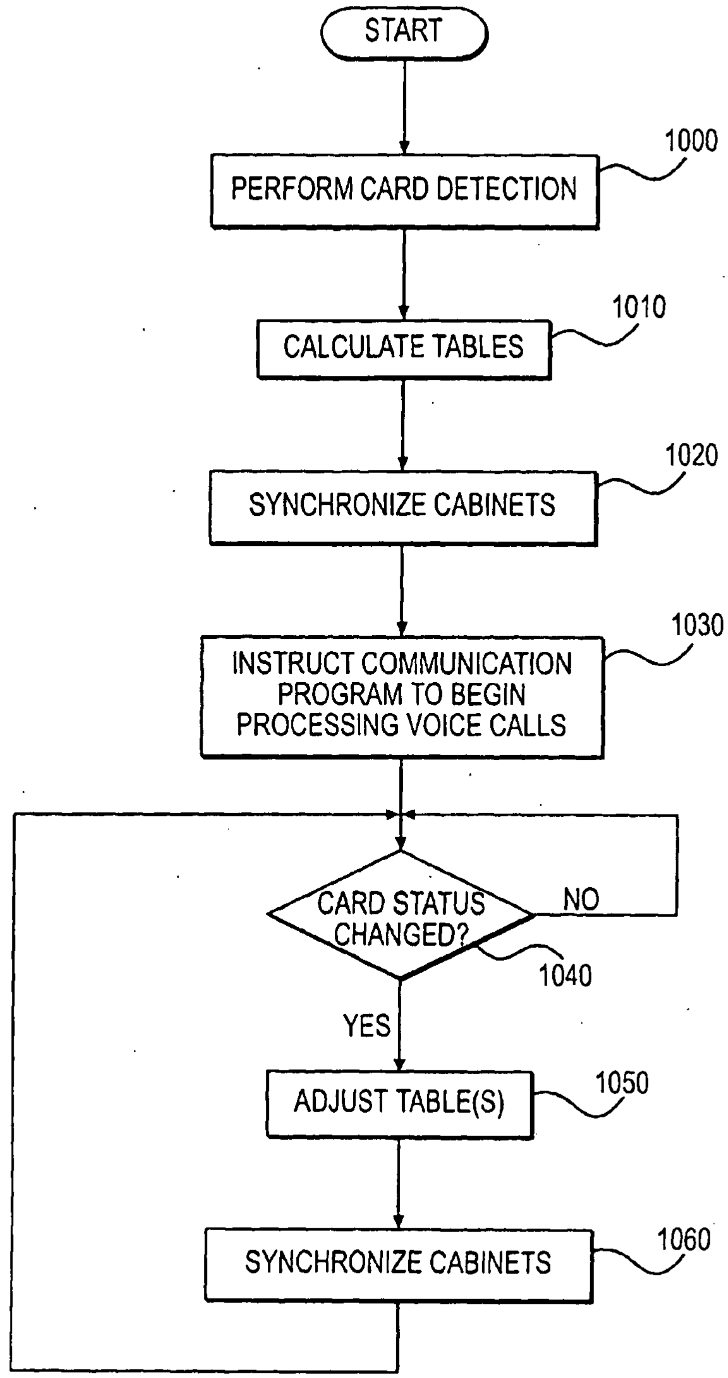
START
PERFORM CARD DETECTION
1000
CALCULATE TABLES
1010
SYNCHRONIZE CABINETS
1020
INSTRUCT COMMUNICATION PROGRAM TO BEGIN PROCESSING VOICE CALLS
1030
CARD STATUS CHANGED?
NO
1040
YES
ADJUST TABLE(S)
1050
SYNCHRONIZE CABINETS
1060

FIG. 16

	VALUE = POSITION IN PACKET															
CARD 1 CHANNELS 1-16	1	2	3	4	5	6	7	8	0	0	0	0	0	0	0	0
CARD 1 CHANNELS 17-32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CARD 2 CHANNELS 33-48	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
CARD 2 CHANNELS 49-64	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
CARD 3 CHANNELS 65-80	9	10	11	12	0	0	0	0	0	0	0	0	0	0	0	0
CARD 3 CHANNELS 81-96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CARD 4 CHANNELS 97-112	13	14	15	16	0	0	0	0	0	0	0	0	0	0	0	0
CARD 4 CHANNELS 113-128	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CARD 5 CHANNELS 129-144	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
CARD 5 CHANNELS 145-160	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

1100

FIG. 17

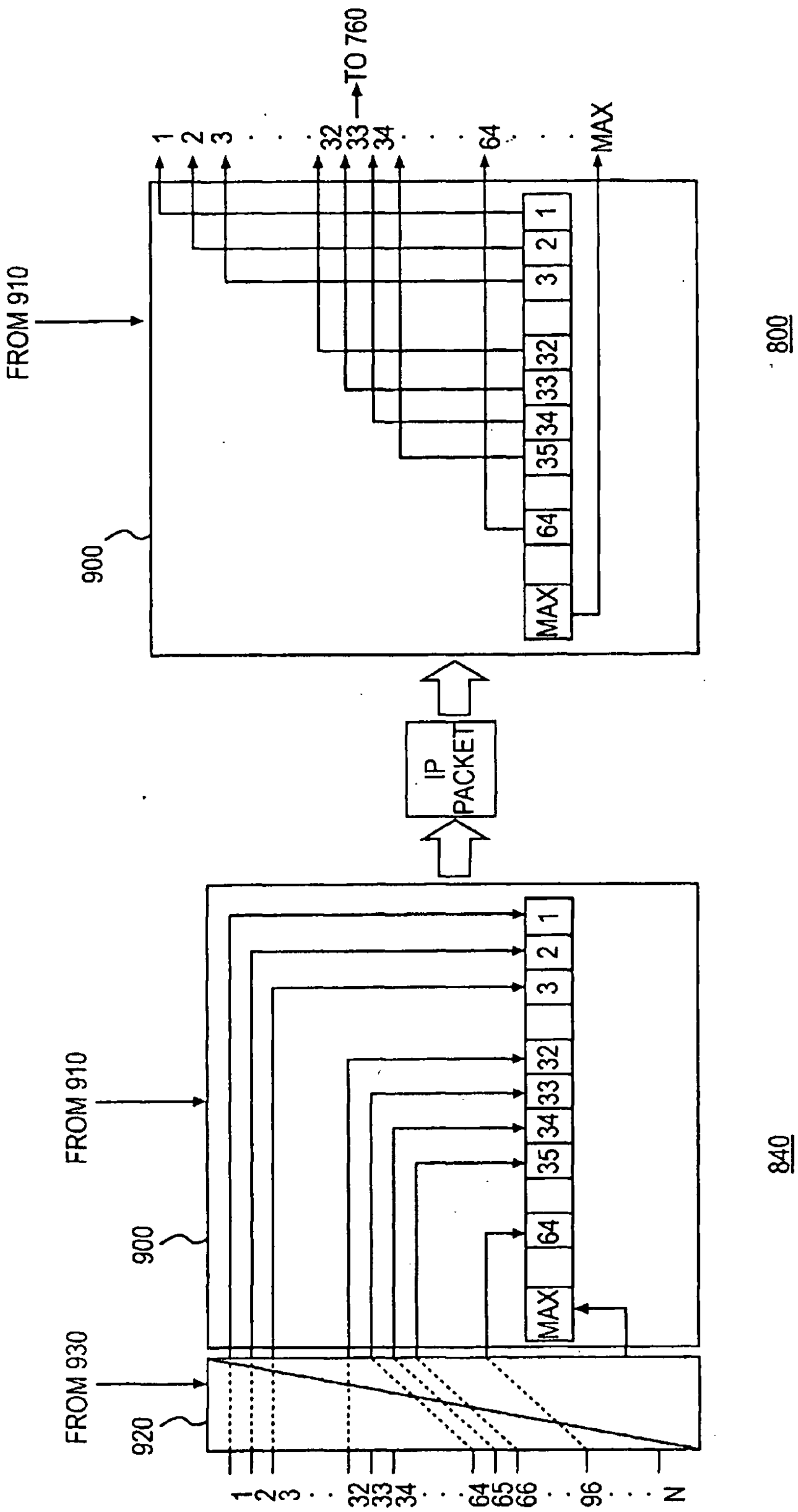
FROM 910
900
1
2
3
32
33
34
35
64
MAX
TO 760
800
IP PACKET
FROM 910
900
FROM 930
920
840
N
65
66
96

FIG. 18

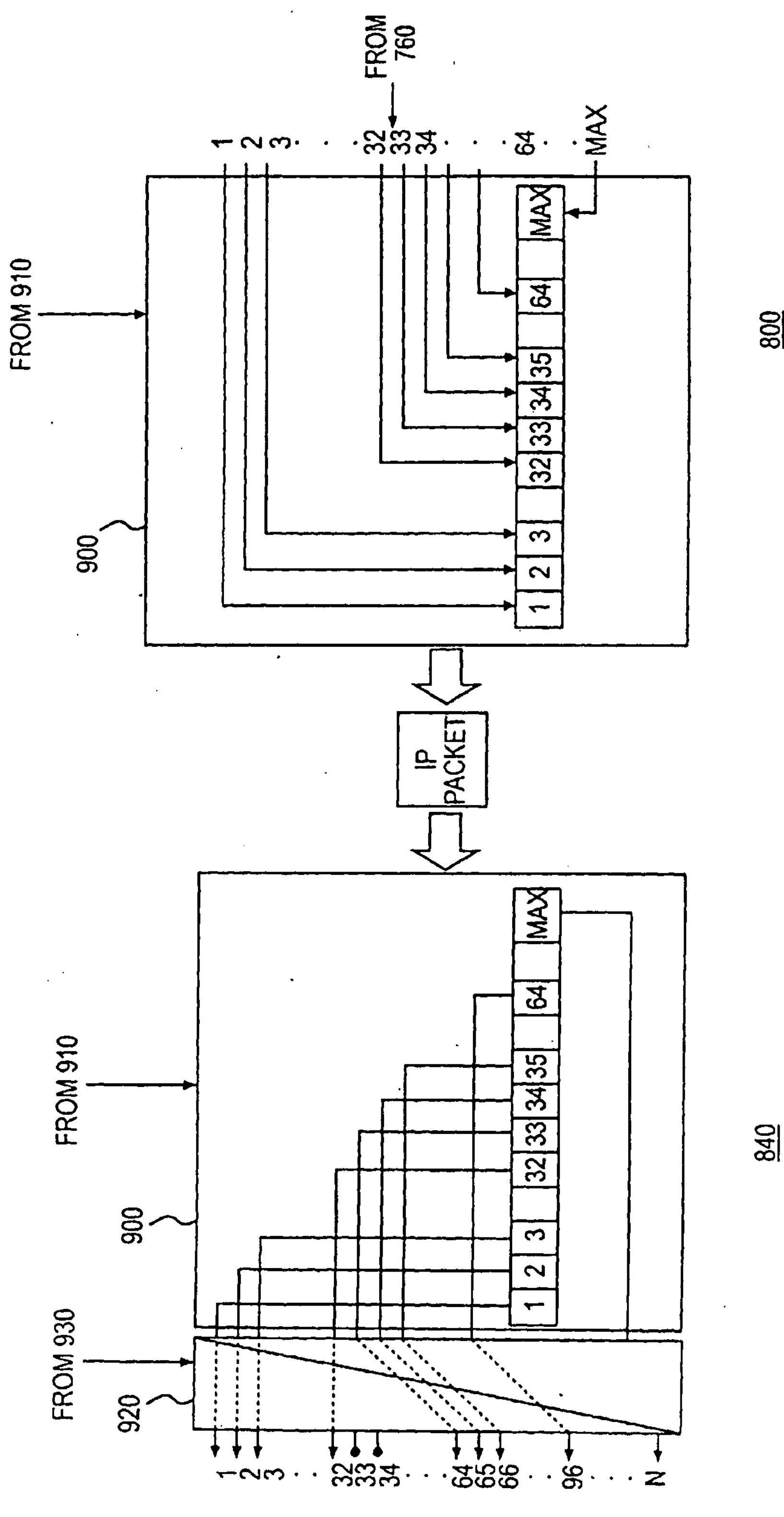
FROM 910
FROM 760
900
1 2 3 . . . 32 33 34 . . . 64 . . . MAX
1
2
3
32
33
34
35
64
MAX
800
IP PACKET
FROM 910
900
FROM 930
920
1 2 3 . . . 32 33 34 . . . 64 65 66 . . . 96 . . . N
840

FIG. 19

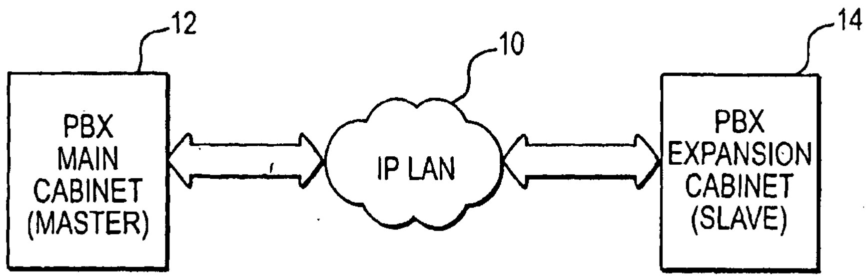

FIG. 20

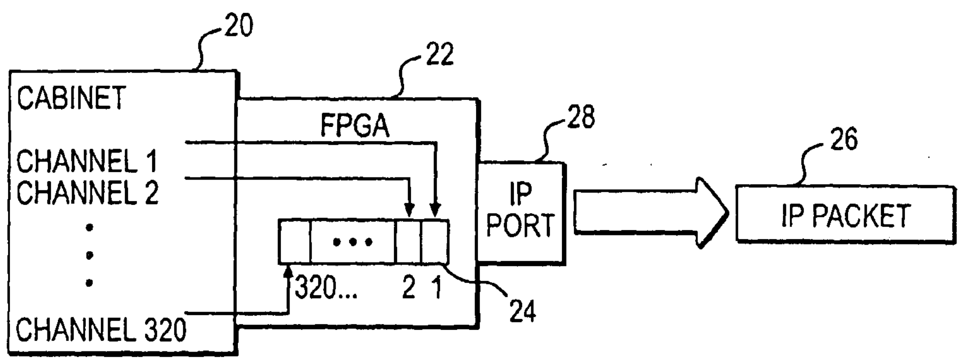

FIG. 21

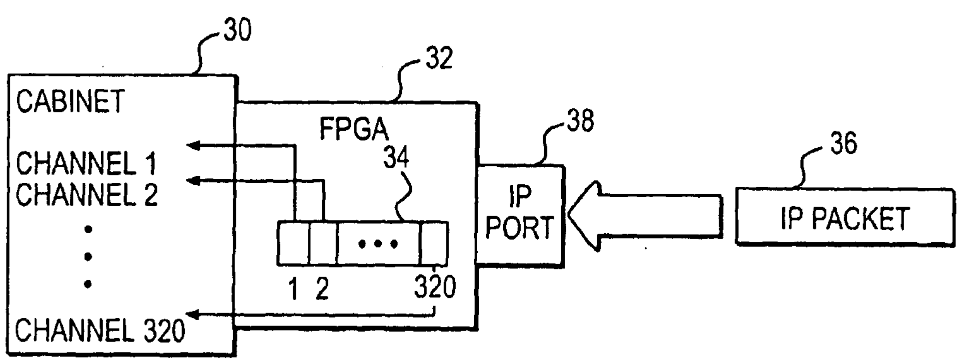

FIG. 22

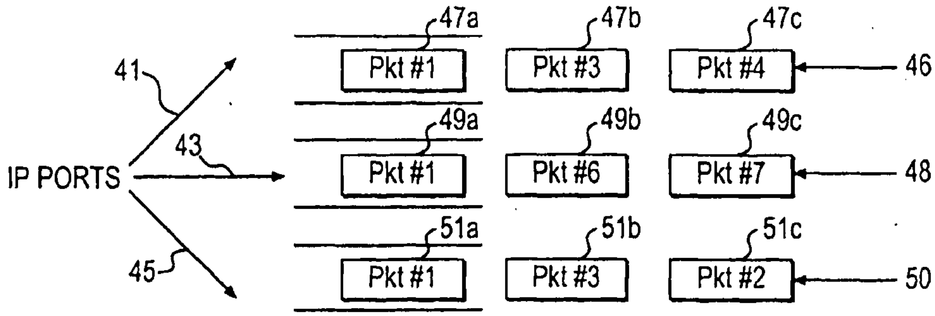

FIG. 23a

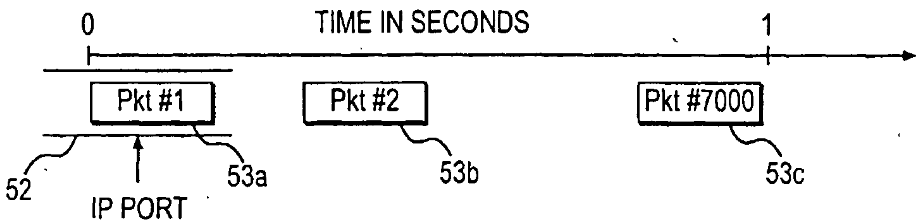

FIG. 23b

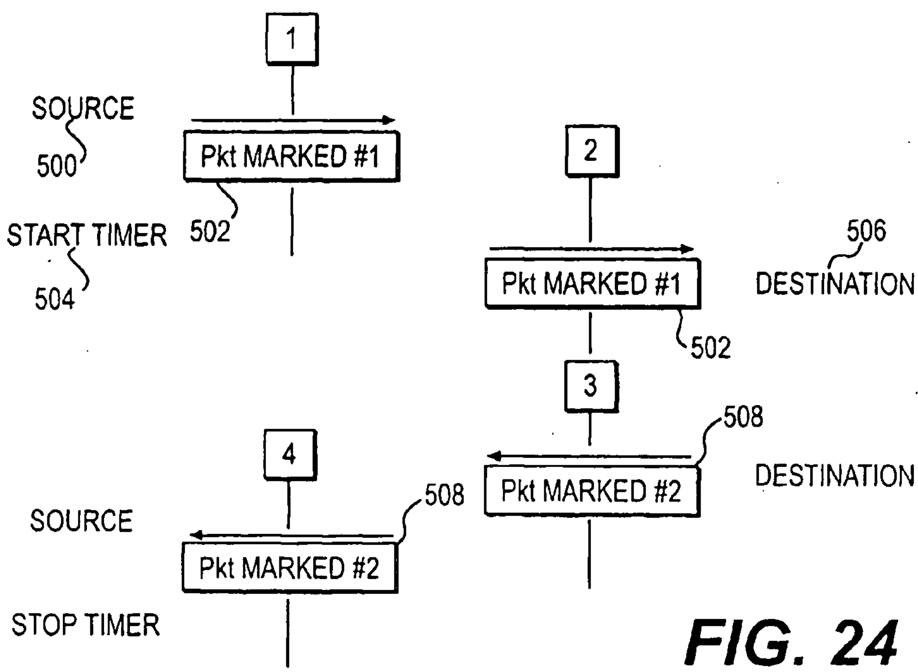

FIG. 24

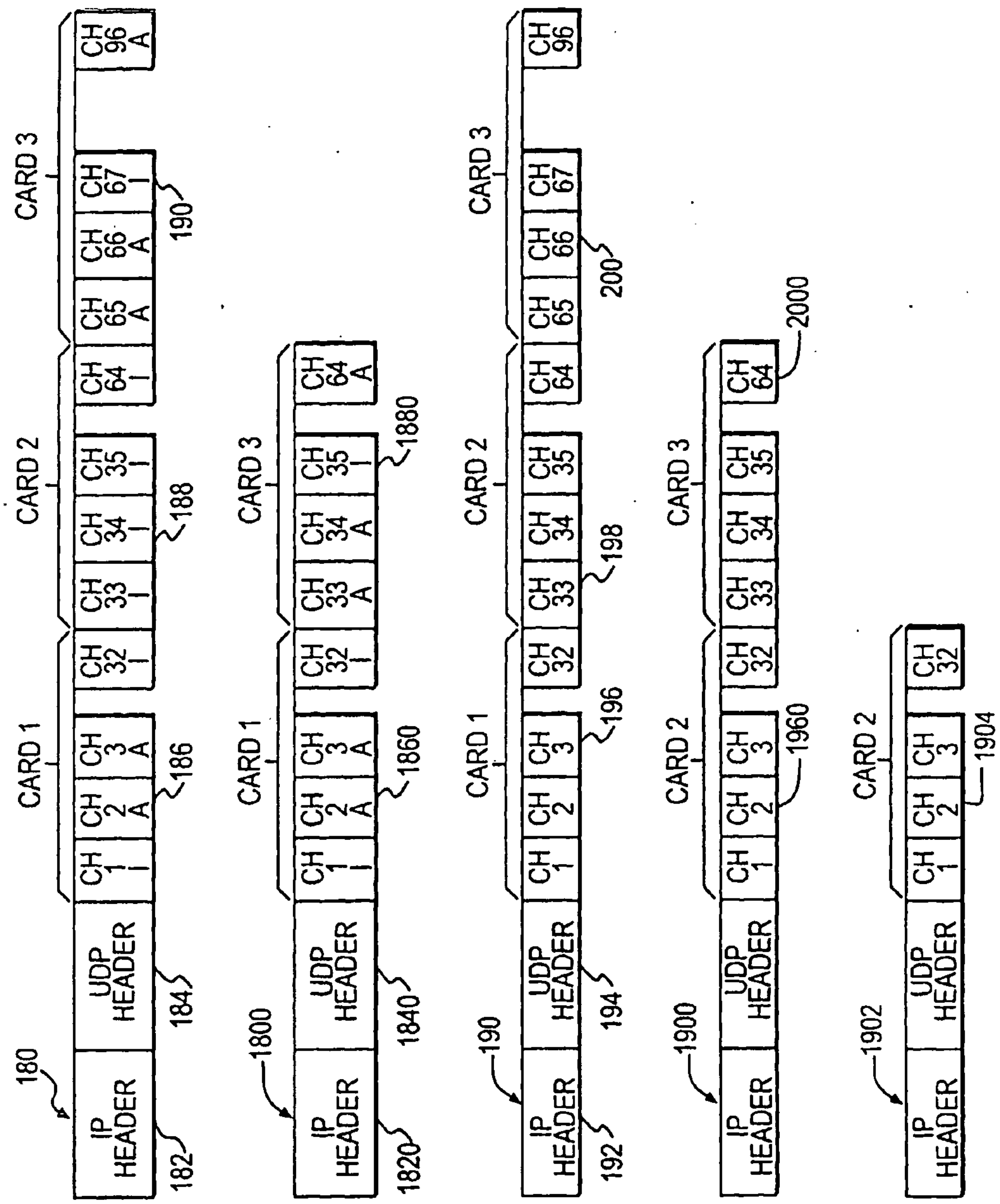

FIG. 25a

FIG. 25b

FIG. 26a

FIG. 26b

FIG. 26c

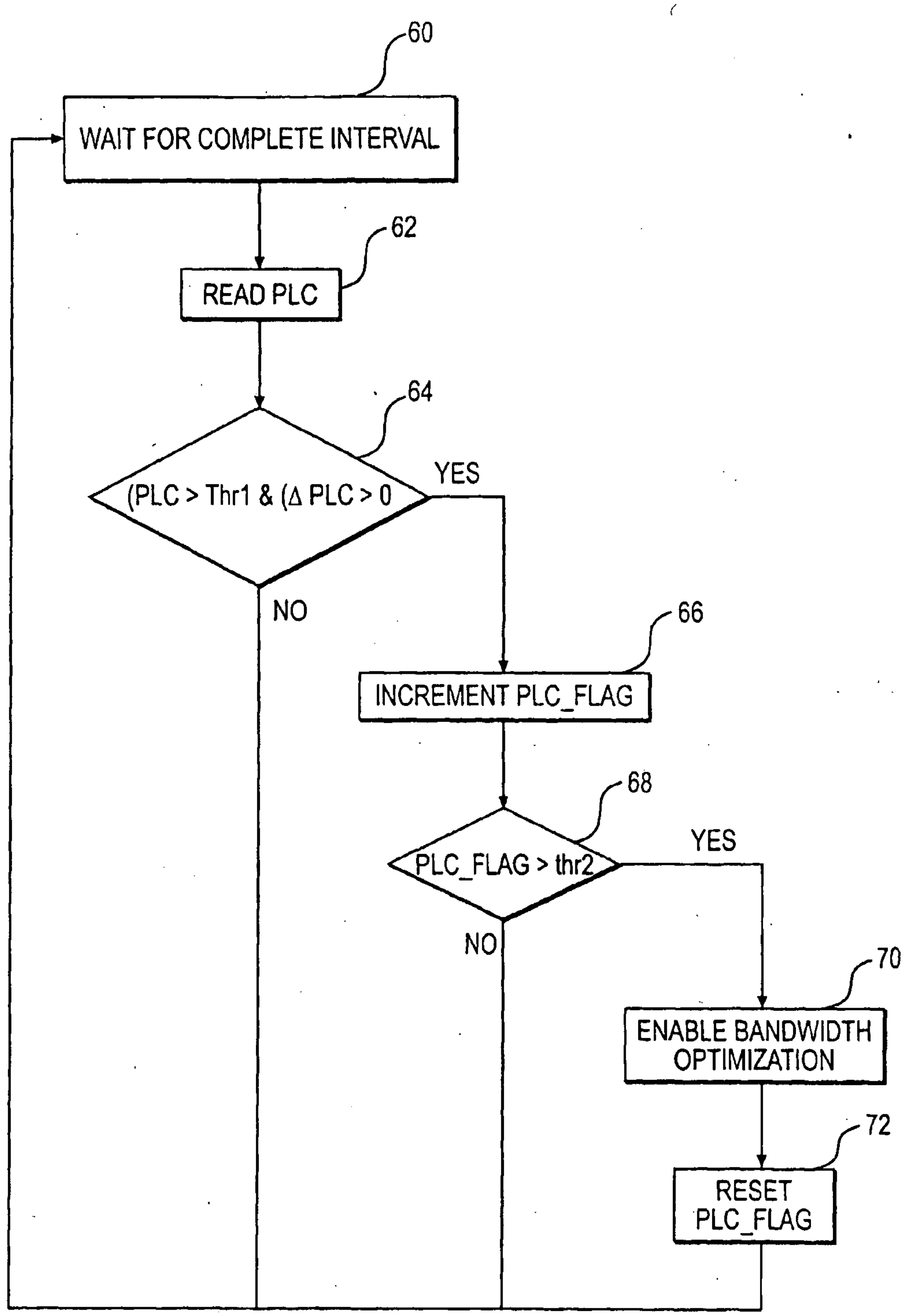
60
WAIT FOR COMPLETE INTERVAL
62
READ PLC
64
(PLC > Thr1 & (Δ PLC > 0
YES
NO
66
INCREMENT PLC_FLAG
68
PLC_FLAG > thr2
YES
NO
70
ENABLE BANDWIDTH OPTIMIZATION
72
RESET PLC_FLAG

FIG. 27

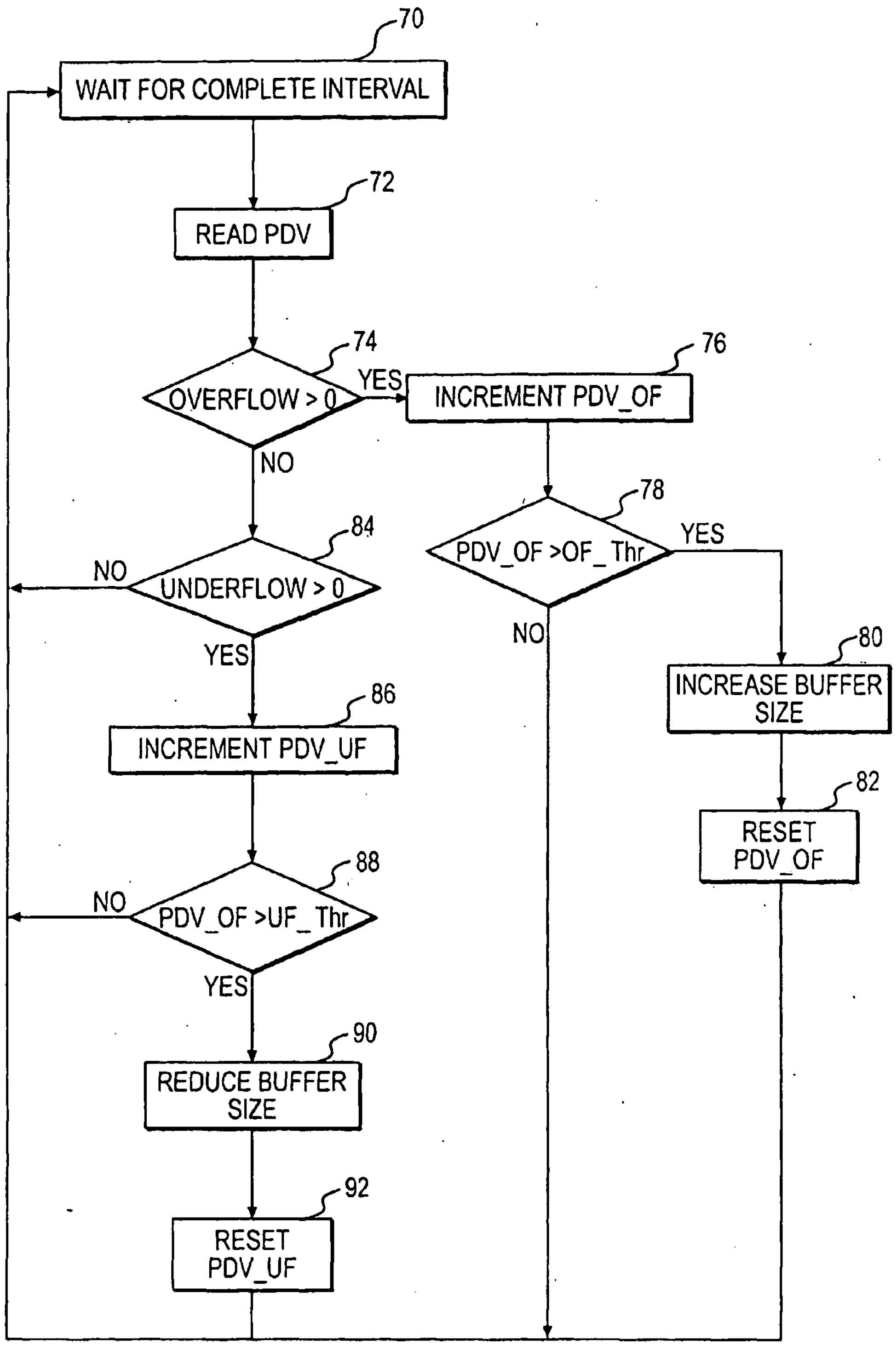
70
WAIT FOR COMPLETE INTERVAL
72
READ PDV
74
OVERFLOW > 0
YES
76
INCREMENT PDV_OF
NO
84
NO
UNDERFLOW > 0
YES
78
PDV_OF >OF_Thr
YES
NO
80
INCREASE BUFFER SIZE
82
RESET PDV_OF
86
INCREMENT PDV_UF
88
NO
PDV_OF >UF_Thr
YES
90
REDUCE BUFFER SIZE
92
RESET PDV_UF

FIG. 28

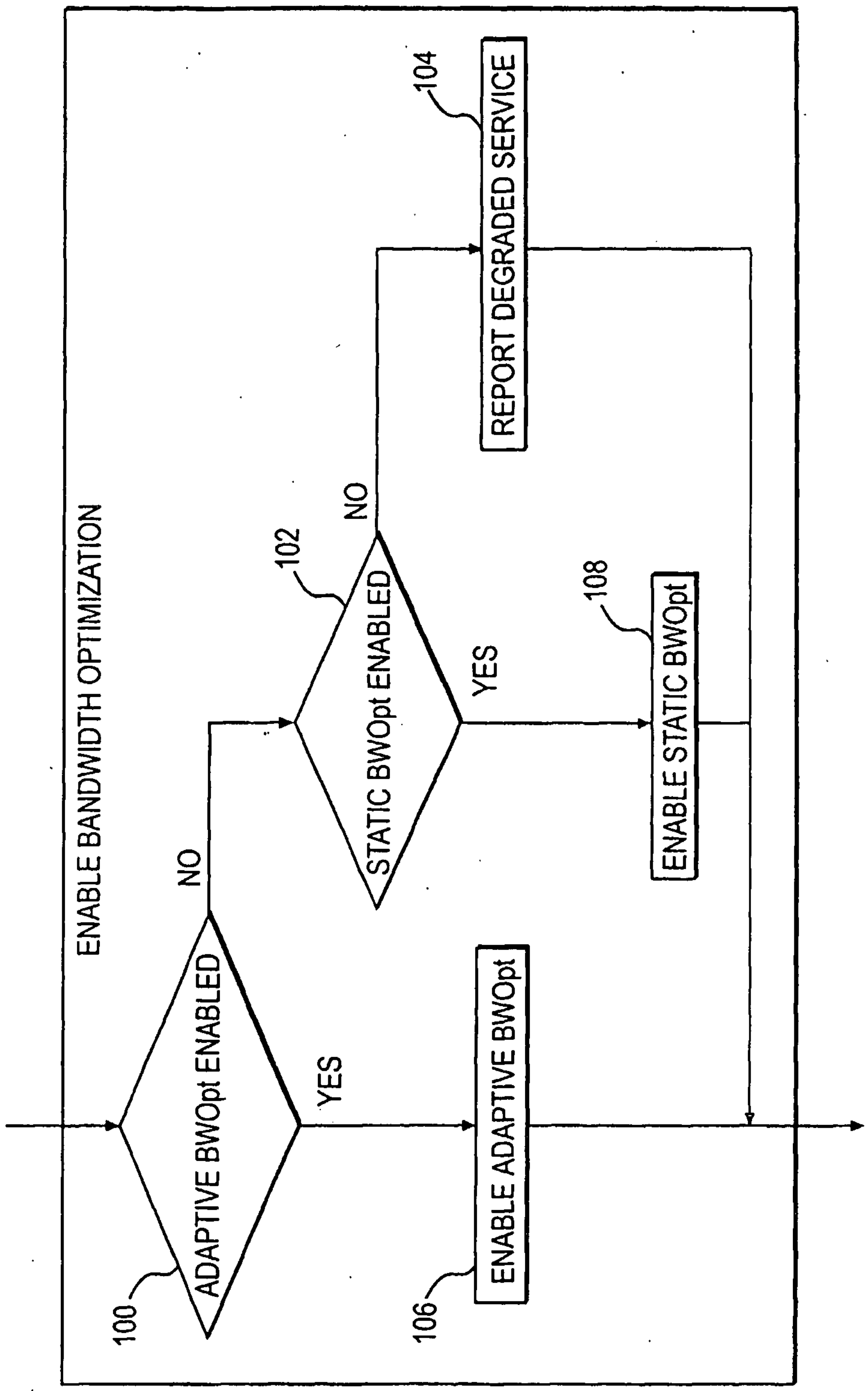
ENABLE BANDWIDTH OPTIMIZATION
100
ADAPTIVE BWOpt ENABLED
YES
NO
102
STATIC BWOpt ENABLED
YES
NO
104
REPORT DEGRADED SERVICE
106
ENABLE ADAPTIVE BWOpt
108
ENABLE STATIC BWOpt

FIG. 29